OCS Study
BOEM 2020-020

Occurrence of Commercially Important and Endangered Fishes in Delaware Wind Energy Areas Using Acoustic Telemetry

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DISCLAIMER

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ABOUT THE COVER

Captain Wes Townsend redeploys an acoustic receiver mooring in the Delaware Wind Energy Area array in the early morning.

ACKNOWLEDGMENTS

We would like to extend our sincere gratitude and thanks to Brian Hooker (BOEM) for his role in administering project funding. Members of the Atlantic Cooperative Telemetry (ACT) Network graciously provided species identification of fish detected during this project. In particular, we thank Dr. Dave Secor and Ellie Rothermal for their contributions to the project. We thank Dr. Vince Guida, MARACOOS, and Rutgers University for the environmental data used in our analyses. We appreciate the invaluable field assistance provided by Captain Kevin Wark for expertise in the safe capture and firsthand knowledge of Atlantic sturgeon in the mid-Atlantic region. In addition, we are grateful for the assistance of Captain Wes Townsend with designing, deploying and maintaining the acoustic telemetry receivers.

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Executive Summary

The Mid-Atlantic Bight has been identified as an area with great offshore wind potential, creating interest in the development of offshore wind energy projects in Wind Energy Lease Areas (WEAs). The Delaware (DE) WEA starts approximately 11 km off the coast, but little information about the distribution and occurrence of marine species in this area is known. Between 2017-2019, an extensive acoustic telemetry project monitored the timing and location of Atlantic sturgeon, winter skate, and other acoustically telemetered species in the DE WEA (Figure 1). This study was conducted to better understand the potential of encountering these species during future development in the DE WEA, as well as address potential impacts to commercial fisheries. The primary objectives of this study were: (1) Acoustically tag additional Atlantic sturgeon (n=50) and winter skate (n=50) in the DE coastal ocean (2) Deploy an acoustic receiver array for two years in the DE WEA (3) Determine seasonal usage of Atlantic sturgeon, winter skate and other acoustically telemetered species as provided by the ACT Network in the DE WEA (4) Develop environmentally driven models of Atlantic sturgeon and winter skate in the DE WEA (5) Determine transit times of acoustically telemetered species in the DE WEA and nearby coastal ocean (6) Deliver acoustic detection data to acoustic telemetry networks (ACT, MATOS, OTN) (7) Compare the recovery efficiency of standard and acoustic release receivers. Our key findings are highlighted below:

(1) Acoustic detections from all receivers in the array documented the presence of 26 different marine fish and mammals, which creates a baseline to inform future monitoring efforts.

(2) Atlantic sturgeon occurred in the DE WEA nearly year-round, however distribution shifted from the shallow northwestern corner in the spring-summer, to the deeper offshore waters in the fall and winter. Atlantic sturgeon detections were highest in November and December, with far fewer Atlantic sturgeon detections during the summer, especially August. These observations expand upon previous studies for Atlantic sturgeon which characterized their occurrence as much more seasonal than documented in our study. Patterns in the timing and distribution of Atlantic sturgeon were consistent between years.

(3) Using detections from collaborators monitoring the Maryland (MD) WEA and our detections in the DE WEA, we estimated the transit rates for Atlantic sturgeon migrating north in the spring, and south in the fall. Transit rates were consistent with those reported by other studies in the Mid-Atlantic. In addition, we quantified residency behavior in the DE WEA, which was highest in November and December. This provides further evidence that these months are likely when there is the greatest risk of encountering Atlantic sturgeon in the DE WEA.

(4) A generalized additive model (GAM) was created to predict the occurrence and distribution of Atlantic sturgeon using remotely sensed ocean surface parameters (temperature, color), modeled ocean bottom temperature, and seafloor characteristics (bathymetry, sediment grain size, and bottom temperature). This model expands upon similar models produced for Atlantic sturgeon in the area but captures the distribution of Atlantic sturgeon further offshore than previously observed. Model outputs reflect the seasonality of the distribution and occurrence of Atlantic sturgeon in the DE WEA. We also show selection for coarse sand by Atlantic sturgeon for the first time in this region.

(5) Few tagged winter skate were detected in the DE WEA, indicating that there is a low risk of impacting the commercial stock of winter skate due to offshore wind development in this WEA. The few winter skate that briefly entered the DE WEA did so in the spring and fall. Based on the acoustic detections of all tagged species detected, it appears the spring and fall are important

seasons in the study region, with high numbers of species occurring in the DE WEA. This is presumably related to the seasonal migrations of these species.

(6) We observed a large variety of elasmobranch species occurring in the DE WEA, mostly during the summer months. In addition, we detected two marine mammals (seals), which entered the DE WEA in the spring. Further research is needed to better understand the occurrence and distribution of these species in this region, and to establish baselines for their abundance pre-development.

(7) While not a focal species, we noted a high number of detections of striped bass; a species which supports a large commercial and recreational fishery. Striped bass occurrence was highly seasonal, with fish occurring in high numbers in November through January slightly more inshore and in March through May slightly more offshore.

(8) Our study demonstrated the utility of acoustic-release transceivers, which minimized gear loss and enabled more reliable data collection of acoustic detections for tagged marine animals in this region. In addition, acoustic-release receivers allowed us to quantify excess ambient noise in the study region due to seafloor mapping efforts being conducted in anticipation for offshore wind energy development in the DE WEA.

1 Introduction

Technological advances and recent changes in national energy policy objectives have increased the interest in offshore wind energy. The mid-Atlantic continental shelf, which includes Delaware, has been identified by the National Renewable Energy Laboratory as the US coastal region with the greatest offshore wind resource potential in waters less than 60 m deep and therefore is very well suited for near-term offshore wind energy technology (Musial and Ram 2010). This region also supports many commercial and recreational fisheries that contribute significantly to the coastal economy. A challenge with managing a multi-use coastal ocean is developing a spatial management plan that accounts for the dynamic nature of marine species distributions and human activities (Foley et al. 2010). At present, there is limited site-specific information on the seasonal patterns of distribution and habitat use of economically important species (e.g. striped bass, spiny dogfish, summer flounder, and winter skate) as well as species protected under the Endangered Species Act (e.g. Atlantic sturgeon), in and around the proposed offshore wind energy areas in DE. This information is necessary for BOEM to minimize interactions with these species for compliance with the National Environmental Policy, Endangered Species, and Magnuson-Stevens Fishery Conservation and Management Acts.

The Mid-Atlantic Bight coastal ocean is shallow, and the warm summers and cold winters in the Northeast US cause large seasonal changes in sea temperature that drive large scale migrations of commercially important and protected species. While this shallow region may appear featureless, ancient river channels, sand waves and heterogeneous substrate distributions may also influence the occurrence and distribution of marine species, especially those that are benthically associated. In this study, we focused on the federally protected Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) and the commercially important winter skate (*Leucoraja ocellata*), through the use of a passive acoustic telemetry array deployed around the perimeter of the Delaware Wind Energy Lease Area (DE WEA). Both of these species are associated with the benthos and are thought to seasonally occur in the study region. Although our primary focus was these two species, we also leveraged an additional 48 species of acoustically telemetered marine fishes, sea turtles and mammals totaling 4,509 active tags currently registered in the Atlantic Cooperative Telemetry (ACT) Network database.

Sturgeons (family *Acipenseridae*) are highly subject to overexploitation and extinction leading to their recognition as the most imperiled group of organisms on the IUCN Red List (IUCN 2010). Atlantic sturgeon experienced severe declines due to habitat destruction and overfishing beginning in the late 19th century. Lack of recovery coupled with concerns over continued loss/degradation of habitat, ship strikes, and bycatch in commercial fisheries resulted in NOAA-NMFS listing five Distinct Population Segments (DPS) under provisions of the Endangered Species Act in 2012 (United States Office of the Federal Registry. 2012). The mid-Atlantic, which includes the Delaware and Hudson Rivers, historically supported the largest populations of Atlantic sturgeon (Secor and Waldman 1999). While there is a growing body of information on the riverine habitat requirements for this species, information on their marine habitats is severely lacking (Dunton et al. 2010; Erickson et al. 2011; Oliver et al. 2013). Studies in the Mid-Atlantic Bight have shown evidence that Atlantic sturgeon seasonally migrate along the East Coast of the U.S. and through the Mid-Atlantic Bight, but these studies have been limited to the nearshore environment (< 16 km; Erickson et al. 2011; Breece et al. 2018). This lack of information on marine habitat use is of particular concern given the fact that Atlantic sturgeon spend the vast majority (>90%) of their adult lives in coastal and offshore waters and are completely dependent on this region for food resources. Atlantic sturgeon are a large (max weight > 400kg) and highly mobile species, as a result they are not commonly encountered in traditional gillnet or trawl surveys due to issues surrounding gear selectivity (Dunton et al. 2010). Telemetry is therefore a much more effective technique for understanding the seasonal presence, habitat use and movement pathways of sturgeon.

Similar to sturgeons, skates (family *Rajidae*) are highly vulnerable to overexploitation due to a combination of life history traits (Swain et al. 2005). Once widely considered a “trash fish” the winter skate, one of the largest and most common skates in mid-Atlantic and New England waters, now supports large scale gillnet and trawl fisheries throughout much of its range (Frisk et al. 2008). At present there is growing concern over the long-term sustainability of these fisheries resulting in calls for improved data to manage this species (Kelly and Hanson 2013). Winter skates are commonly found on sandy to gravelly bottom in waters shallower than 111m (McEachran and Musick 1975) and are known to occur in the DE WEA, although information required to develop environmentally driven occupancy models are not available at this time (Packer et al. 2003). Beyond their commercial value, Winter skate play a key role in structuring benthic communities through their foraging (Link 2007). Based on conventional mark-recapture and trawl surveys, winter skate are believed to make both inshore-offshore and north-south migrations based on relative age/sex and time of year (Packer et al. 2003) although we are not aware of any telemetry studies providing finer scale information.

At the conclusion of this two-year survey, we have a baseline dataset of the occurrence and distribution of our focus species, as well as over 20 additional telemetered species that traveled through the acoustic array. These results will help establish pre-construction standards of marine animal behavior, occurrence and distribution in the DE WEA.

1.1 Project objectives

The main objective of this study was to provide information on the seasonal patterns of occurrence and habitat use as well as explore the underlying causal mechanisms and environmental correlates for Atlantic sturgeon and winter skate habitat selection in the DE WEA. Our approach provides a robust estimate of Atlantic sturgeon and winter skate distribution and habitat use in the DE WEA through the use of acoustic telemetry arrays. Following the BOEM guidelines for providing information on fisheries for renewable energy development, the specific objectives of this study were to:

1. Acoustically tag additional Atlantic sturgeon and winter skate in the DE coastal ocean.
2. Deploy an acoustic receiver array for two years in the DE WEA.
3. Determine seasonal usage of Atlantic sturgeon, winter skate and other acoustically telemetered species as provided by the ACT Network in the DE WEA.
4. Develop environmentally driven models of Atlantic sturgeon and winter skate in the DE WEA.
5. Determine transit times of acoustically telemetered species in the DE WEA and nearby coastal ocean.
6. Deliver acoustic detection data to acoustic telemetry networks (ACT, MATOS, OTN)
7. Compare the recovery efficiency of standard and acoustic release receivers.

2 Methods - Delaware Wind Energy Area Study Design

2.1 Study Region - Physical Setting

The DE WEA is located approximately 11-23 miles east of Rehoboth Beach, DE (southeast of the mouth of the Delaware Bay), and covers 96,430 acres (Figure 1; Guida et al. 2017). This lease area is located between two shipping channels that lead to the entrance of one of the largest shipping ports in the United States (Figure 1; Mangone 1988). Water depth in the region ranges from 10 to 34 m, with an average of approximately 25 m (Figure 2A; Guida et al. 2017). Previous surveys of the bottom topography in the lease area have documented the presence of several N-S and NE-SW oriented "mega-ripples", with the largest sand ripples in the NW corner (Figure 2; Guida et al. 2017). The bottom substrate consists largely of sediment between -2 to 3 Φ (very fine gravel to fine sand) on the Wentworth scale, with a distinct NE-SW oriented sand channel between areas of coarser sand and gravel (Figure 2B).

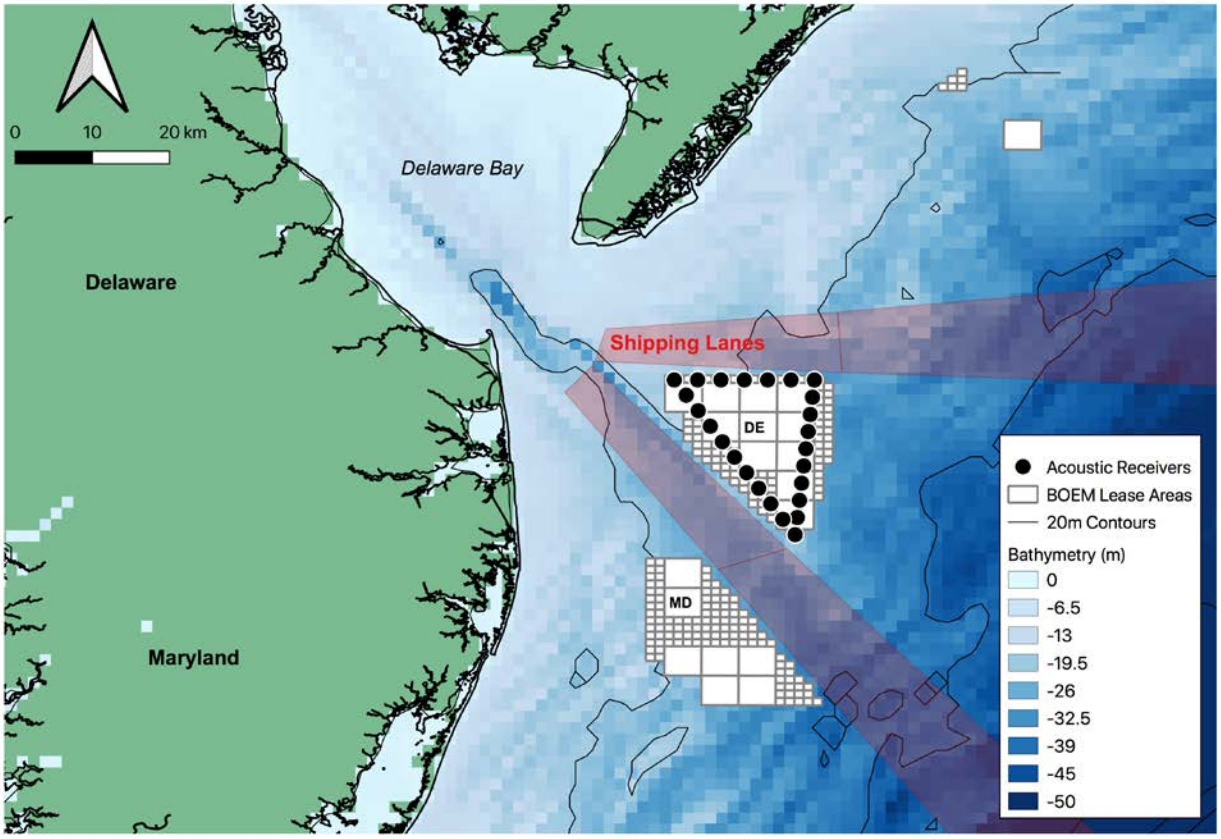


Figure 1. Map of study region.
BOEM Outer Continental Shelf (OCS) wind energy areas off of Delaware and Maryland, and the Delaware Bay shipping lanes. Black points represent locations of VEMCO acoustic receiver stations deployed between 27 Feb 2017 and 23 Feb 2019.

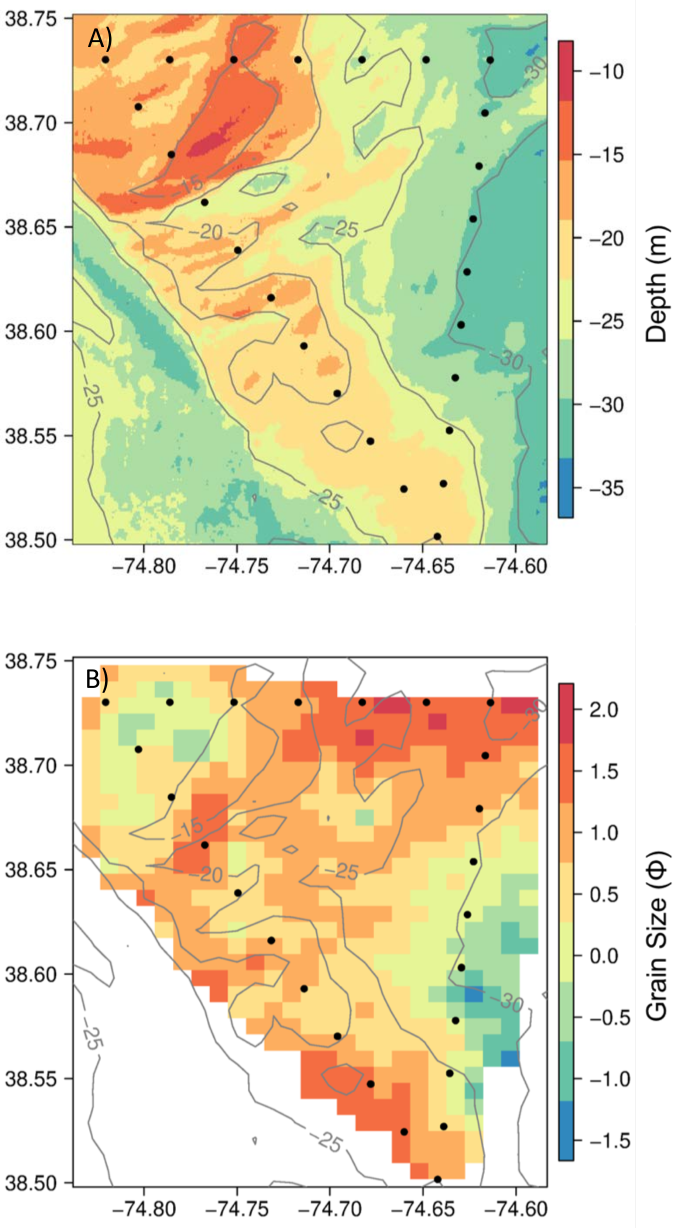


Figure 2. Map of bathymetry and sediment type in DE WEA.

Panel A) Bathymetry data presented is from the NOAA National Centers for Environmental Information, US Coastal Relief Model. Panel B) Sediment grain size (Φ) shown is the interpolated predicted average sediment type (Wentworth Classification) from DE WEA physical samples (adapted from Guida et al. 2017).

2.2 Acoustic Receiver Array

A total of 25 passive acoustic receivers were anchored in gate formations (straight lines) around the perimeter of the DE WEA (Figure 1). Having the receivers arranged around the perimeter of the WEA allowed us to minimize distance between receivers and maximize the probability that telemetered fish would be detected entering and exiting the study area. In addition, having receivers placed at the top and bottom of the WEA would allow us to calculate transit rates as telemetered fish migrated through the array. The original array design consisted of 21 traditional VEMCO VR2W (VEMCO Ltd. Halifax, Nova Scotia), and 4 VEMCO VR2AR acoustic release receivers, allowing us to compare the loss rates of the two different receiver mooring designs in the study region.

2.2.1 Deployment

The design of the acoustic receiver moorings (traditional and acoustic release), was a collaboration between the scientific investigators of the project and commercial pot fisherman, who together have over 70 years of commercial fishing and mooring experience along the Delaware coastal ocean. The VR2W

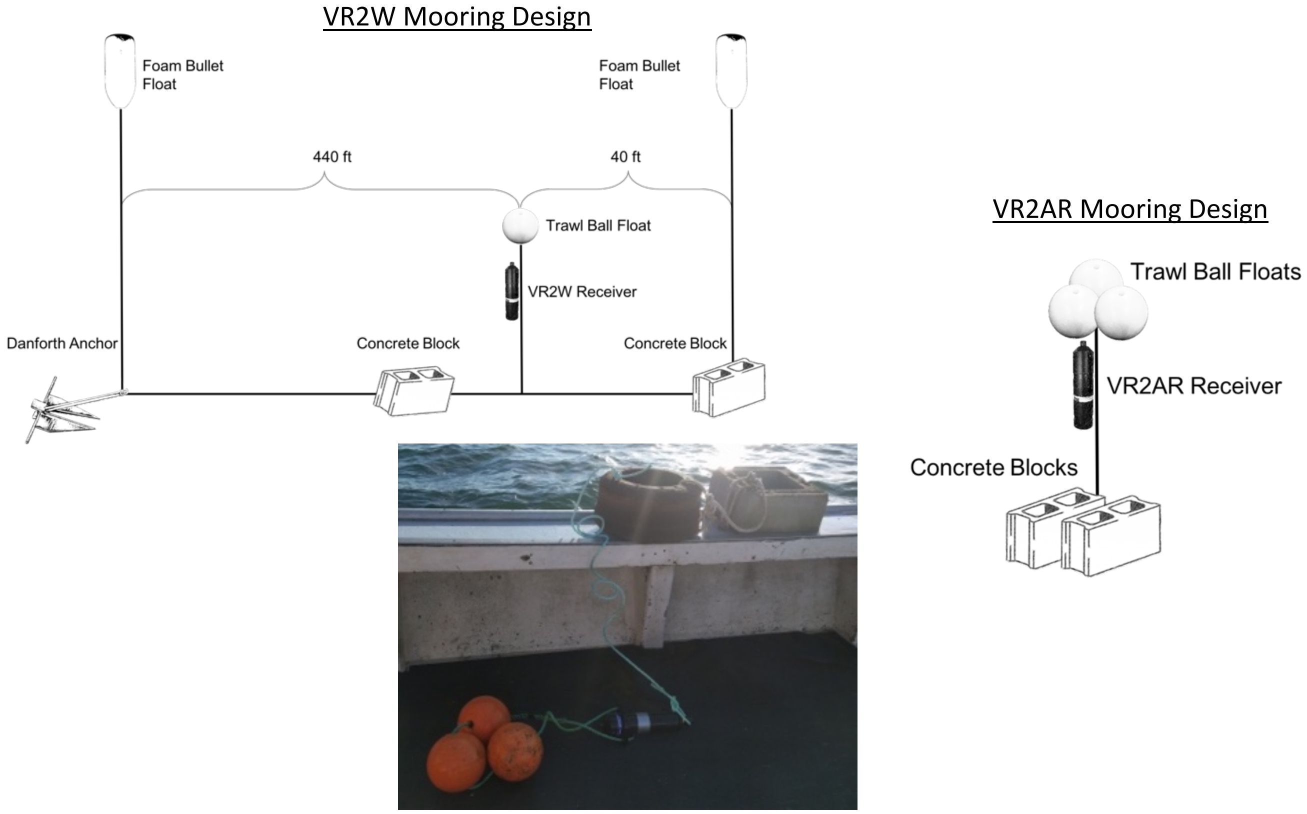


Figure 3. Acoustic receiver mooring designs.
Traditional VR2W acoustic receiver mooring design with redundant surface expression for recovery, and redundant anchoring systems to hold receivers on station. Acoustic release mooring design with nonrecoverable concrete anchors and reusable crush resistant trawl ball floats (also see inset picture).

receiver moorings consisted of two surface floats (attached with weak-links), marking the locations of a Danforth anchor and an 80 lb concrete block connected by a ground line (Figure 3). An acoustic receiver was held upright in the water column, by a crush resistant trawl ball float, approximately 4 m off the seafloor and connected to the ground line. A second concrete block was also attached to the ground line for stability (Figure 3). The second concrete block was added after heavy coastal storms and strong tidal flows caused the receiver moorings to become entangled and move off station. The acoustic release receivers do not require surface expression for recovery and were moored on the bottom by two concrete blocks, with 3-4 crush resistant trawl ball floats holding the receivers upright approximately 4 m off the seafloor (Figure 3). Acoustic receivers were deployed 27 February 2017 and spaced at approximately 3 km intervals along the northern, western and eastern edges (Figure 1). Acoustic detection range is estimated to be approximately 1 km, so while there was no overlap in detection ranges between receivers, this distance maximized receiver coverage given the number of receivers available for this study.

2.2.2 Maintenance and Recovery

The acoustic receiver array was maintained on an approximately bi-monthly basis depending on weather and vessel availability. All maintenance occurred from a commercial pot fishing vessel. The majority of the maintenance trips were conducted on a single day, although occasionally two separate trips were needed to maintain all 25 receivers. During each maintenance trip, traditional VR2W receiver moorings were recovered and biofouling was removed from lines, floats and receivers. Occasionally, strong tidal flows or coastal storms caused the mooring to become tangled, often holding one surface float under water until the mooring was untangled. Often, one of the surface floats was missing, likely cut off by vessels passing through, and required replacement. After each mooring was recovered, the acoustic receiver was downloaded, and the mooring was redeployed. If a mooring was unable to be located by the surface expression, echosounder or grapple, or the receiver was missing from the mooring, it was replaced with a spare, or converted to an acoustic release station if receiver loss at that station was persistent.

Acoustic release receivers were not downloaded on every maintenance trip to reduce the number of sacrificial anchoring mechanisms used. In addition, the absence of any surface expression meant that there were fewer interactions between vessels and the acoustic release moorings. If the VR2AR was not acoustically released from its mooring for download, the status (battery, depth, tilt angle, memory) was checked using the VEMCO VR-100 and transponding hydrophone. Occasionally moorings were shifted off station 500 m when it was determined the presence of fishing activity (sea bass pot fisherman in the NE corner), or shipping activity (tanker ships anchoring in the S corner) were likely to, or already had, interfered with our moorings (Figure 4).

The acoustic receiver array was recovered during multiple trips between 30 March 2018 and 1 June 2018. Acoustic detection data for analysis was constrained between 27 February 2017 and 23 February 2019 to cover 2 full calendar years with near complete coverage by the array.

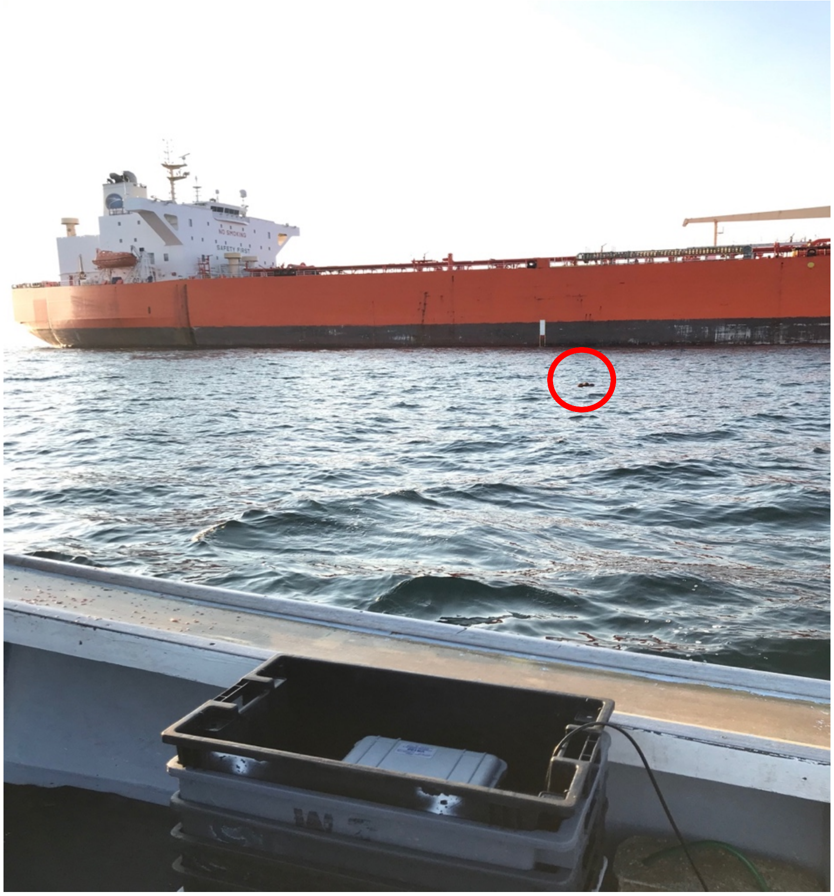


Figure 4. Photo demonstrating the proximity to acoustic release receiver station.
Trawl ball floats attached to acoustic release receiver are circled in red.

2.2.3 Acoustic Telemetry Data Distribution

The Atlantic Cooperative Telemetry (ACT) Network was critical to the success of our project. While we deployed 100 additional acoustic transmitters associated with Atlantic sturgeon and winter skate as part of this project (Section 3), approximately 55% of the individual acoustic transmitters in marine animals detected in this study were associated with species other than our focal species. During our two-year study, receivers in the DE WEA array recorded 124,710 detections, from 899 transmitters, belonging to 49 different researchers or research collectives. Of the 899 transmitters, we were able to identify the species associated with 877 of the transmitters (Table 1). Detections were distributed via email to the researcher associated with the transmitter code in the ACT Network database on a bi-monthly to quarterly basis. Upon completion of the study, detections of transmitters that were unable to be identified through the ACT network were sent to VEMCO who alerted the researcher of our project. This process allowed us to identify 132 of the 899 total transmitters detected, belonging to 13 of the 49 researchers.

Table 1. Cumulative number of individuals per species detected on DE BOEM acoustic array between deployment 27 Feb 2017 and recovery 23 Feb 2019.

Common Name	Scientific Name	No. of Individuals	Common Name	Scientific Name	No. of Individuals
American shad	*Alosa sapidissima*	2	Sandbar shark	*Carcharhinus plumbeus*	14
Atlantic angel shark	*Squatina dumeril*	1	Sand tiger shark	*Carcharias taurus*	15
Atlantic bluefin tuna	*Thunnus thynnus*	2	Smooth dogfish	*Mustelus canis*	13
Atlantic cod	*Gadus morhua*	2	Southern stingray	*Hypanus americanus*	1
Atlantic sturgeon	*Acipenser oxyrhynchus oxyrhyncus*	360	Spinner shark	*Charcharhinus brevipinna*	1
Black sea bass	*Centropristis striata*	4	Spiny dogfish	*Squalus acanthias*	7
Blacktip shark	*Carcharhinus limbatus*	29	Striped bass	*Morone saxatilis*	320
Bull shark	*Carcharhinus leucas*	2	Summer flounder	*Paralichthys dentatus*	1
Cobia	*Rachycentron canadum*	5	Thresher shark	*Alopias vulpinus*	3
Cownose ray	*Rhinoptera bonasus*	3	Tiger shark	*Galeocerdo cuvier*	2
Dusky shark	*Carcharhinus obscurus*	20	White shark	*Carcharodon carcharias*	56
Gray seal	*Halichoerus grypus*	1	Winter skate	*Leucoraja ocellata*	13
Harbor seal	*Phoca vitulina*	1	Not identified		22

3 Methods - Atlantic Sturgeon and Winter Skate Tagging

To supplement the existing populations of acoustically telemetered Atlantic sturgeon and winter skate, we deployed 100 additional VEMCO acoustic transmitters (50 each species). This ensured that there was an adequate number of active transmitters in our focal species that were captured in close proximity to the DE WEA and reduced our reliance on transmitters deployed by other research groups.

3.1 Fish Sampling

Figure 5. Fish sampling aboard F/V Dana Christine.
Captain Kevin Wark, Michael Lohr and Dr. Danielle Haulsee (L-R) watch as gill net is reeled onto drum. Wooden live well (bottom left) contains an adult Atlantic sturgeon under anesthetic.

Sampling for adult and large sub-adult Atlantic sturgeon and adult winter skate was conducted in the spring of 2017, during their coastal migration along the Delaware coastline. The timing and location (approximately 20 km to the SW of the DE WEA based on knowledge of high densities of these animals from prior research and fishing experience) of sampling was adapted to minimize potential interactions with marine mammals as well as to intercept the coastal movements of Atlantic sturgeon and Winter skate. Sampling for adult sturgeon and large sub-adult Atlantic sturgeon, as well as adult Winter skate, was conducted simultaneously using anchor gill nets. Nets were built and fished in compliance with both the Harbor Porpoise Take Reduction Requirement as well as the Atlantic Large Whale Take Reduction Program. Nets were fished in accordance with developed protocols (Damon-Randall et al. 2010) and sampling was conducted in compliance with the NOAA- NMFS permit to take protected species for scientific purposes #16507.

Between 2 April 2017 and 7 May 2017, we sampled on 16 days, and deployed 70 gill net sets. Each set consisted of up to twenty monofilament anchor gillnet panels (91.0m x 6.1m) strung together and fished as one long net. Nets had mesh sizes ranging from 30.5 to 33.0 cm stretch, with twine sizes ranging from 0.92-0.98mm, and a hanging ratio of 0.5. During suitable conditions, up to two nets were fished at the same time and were tended every 2-4 hours to reduce bycatch and minimize stress and/or potential mortality of Atlantic sturgeon and Winter skate. Gillnets were compliant with large whale take reduction measures and outfitted with acoustic pingers (Fumunda, 10 kHz, 132 dB) at the beginning of the net and at the junction of each gillnet panel to help deter marine mammal interactions. The GPS coordinates for the both ends of the gillnet were recorded as the set location, as well as the soak time and local environmental conditions (temperature, salinity, dissolved oxygen, depth). In total, 68 Atlantic sturgeon and 199 winter skate were collected during the sampling efforts.

Figure 6. Collecting metadata for adult Atlantic sturgeon and Winter skate in live well. Left Photo: Dr. Danielle Haulsee measuring the fork length and total length of an anesthetized Atlantic sturgeon in preparation for transmitter implantation. Right Photo: Adult Winter skate in live well where it will be the disc width was measured.

Upon capture, all Atlantic sturgeon were placed in a live well with water pumped directly from the sampling site, maintaining ambient temperature, salinity and dissolved oxygen levels (Figure 6, left photo). Total length (TL), fork length (FL) (cm) (Figure 6) and weight (kg) were measured and recorded (Figure 7). Using an AVID® Power Tracker 8, each Atlantic sturgeon was scanned for the presence of an existing PIT tag (passive integrated transponder). If no tag was found, a PIT tag was inserted on the left side of the fish at the base of the dorsal fin (Fuller et al. 2008). Using a PIT tag is common practice among Atlantic sturgeon researchers along the East Coast and allows researchers to track fish economically even if they are not tagged with an acoustic transmitter. A 1-1.5 cm^2 genetic sample was collected from the pectoral fin and placed in 95% ethanol for future genetic analysis.

Date: 4/29/17 56
FL: 167 cm ID: 16165
TL: 194 cm Net ID: 60-1
Wt: 43 kg Vem: 16165
Sex: [✓ M] F U

Genetics	Gonad	Recap	OTC	PIT
✓	✓	N	✓	✓

Figure 7. Atlantic sturgeon with field datasheet before release.
All captured Atlantic sturgeon were photographed with a field datasheet documenting their length (FL and TL), weight, sex (if determined), transmitter information, samples taken, and set captured information. In addition, any injuries or unusual morphologies were photographed and documented.

Similarly, captured winter skate that were appropriate for acoustic transmitter implantation (healthy, and appropriate sex to maintain 50:50 sex ratio) were immediately transferred to a live well with fresh seawater pumped from the sampling site. Disc width (cm, measured at the widest part of the skate) and sex were recorded for each winter skate.

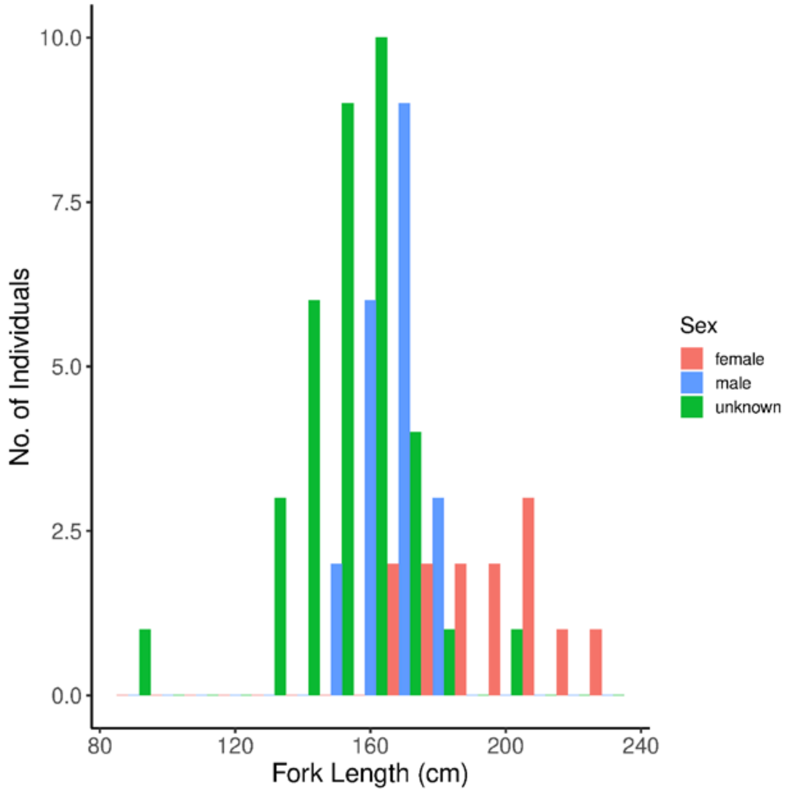


Figure 8. Length frequency for Atlantic sturgeon captured between 2 April 2017 and 7 May 2017.

Bars are colored by the approximated sex of the fish, as determined from gonadal tissue samples taken during the tagging procedure. "Unknown" indicates that the sex was either not able to be determined from gonadal tissue, or the fish was not tagged and no gonadal tissue was sampled.

3.2 Atlantic Sturgeon Transmitter Implantation

As our focus was on adult Atlantic sturgeon (> 1.30 m FL, (Van Eenennaam et al. 1996)), we restricted transmitter implantation to individuals > 1.30 m FL (n=3 Atlantic sturgeon < 1.30 FL). For the 68 Atlantic sturgeon captured, the mean weight was 46.2 kg (range 5-112 kg), and mean fork length was 165.3 cm (range 88-235 cm, Figure 8). We implanted acoustic transmitters (VEMCO V-16, 6-H, 69.0 kHz, 120s duty cycle with an estimated battery life of 10 years), in 50 Atlantic sturgeon (20 male, 18 female and 12 unknown sex) using implantation protocols developed for Gulf sturgeon (*A. o. desotoi*) (Fox et al. 2000) as modified by (Damon-Randall et al. 2010). Anesthetic (tricaine methane sulfonate MS-222®) was added to the live well at a dosage of 50-125 mg/l (Harms and Bakal 1994). When the Atlantic sturgeon could not maintain equilibrium and exhibited signs of slowed respiration, it was placed in a sling, ventral side up, while its head and mouth remained submerged. An incision was made off the centerline of the abdomen; a gonadal tissue sample was taken and placed in a vial containing 10%

buffered formalin for sexual identification and reproductive stage and the transmitter was inserted into the coelomic cavity (Figure 9). Transmitters were coated with Dow Corning Silastic®, a biologically inert silicone elastomer to minimize rejection rates (Boyd Kynard, USGS, Conte Anadromous Fish Laboratory, personal communication). Two to three interrupted sutures were used to close the incision using sterilized suture material (PDSII, size 1, Figure 9). Oxytetracycline was administered as an antibiotic at a dose of 1.0 ml per 20 kg body weight near the base of the dorsal fin. Atlantic sturgeon were allowed to recover in a second live well with fresh seawater and were then released near the location of capture when they returned to an active state.

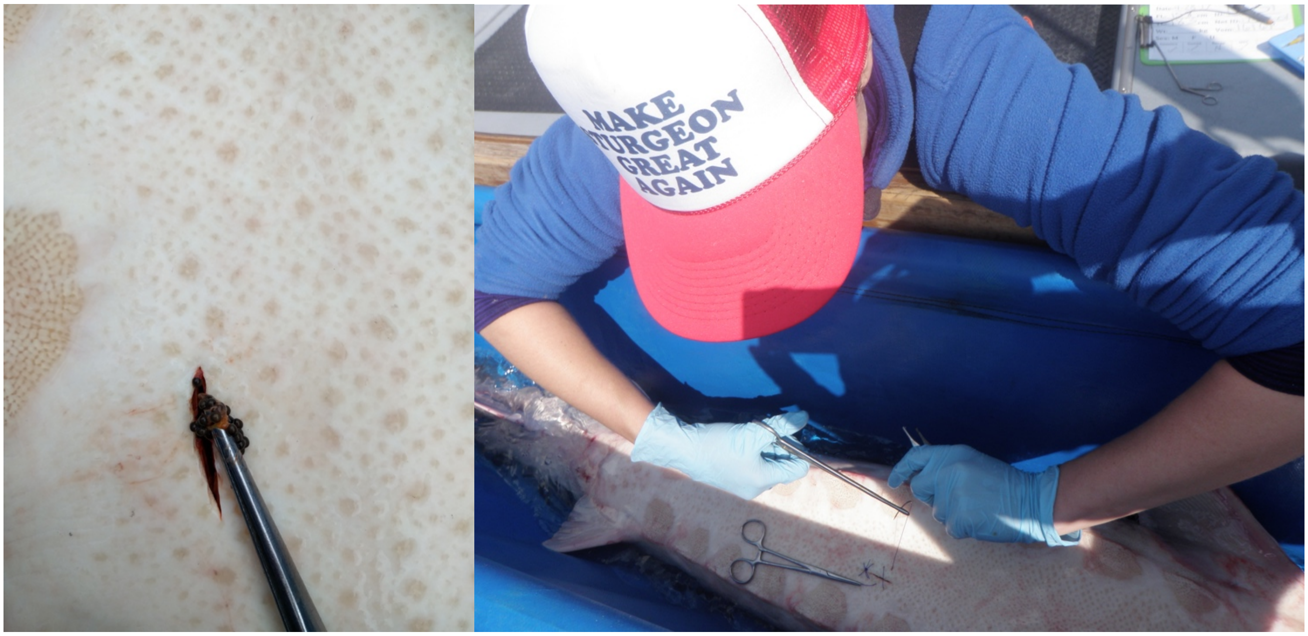


Figure 9. Example of adult female gonadal tissue and interrupted suture closure of incision. Left photo: Black immature oocytes fill the abdominal cavity of an adult female Atlantic sturgeon. Right photo: An anesthetized adult Atlantic sturgeon, implanted with an acoustic receiver, and the interrupted suture incision closure.

3.3 Winter Skate Transmitter Implantation

The transmitter implantation process for winter skates was similar to that for Atlantic sturgeon. Nearly all winter skate collected during sampling were adults (Figure 10). Winter skates were also generally in excellent condition after capture, and we were able to select 25 adult females, and 25 adult males for transmitter implantation. Average disc width for tagged winter skates was 50.6 cm (range 41-60 cm, Figure 10). Winter skates were implanted with a slightly smaller acoustic transmitters (VEMCO V-16, 4-H, 69.0 kHz), to lessen the burden on the winter skate, however these tags were programmed with the same 120 s duty cycle with an estimated battery life of 6.7 years. Like those for Atlantic sturgeon, these transmitters were coated with silicone elastomer to minimize transmitter rejection. In preparation for the implantation surgery, winter skate were placed ventral side up in a shallow water bath, which seemed to induce tonic immobility and caused the skate to become calm enough that anesthetic was not necessary. A small incision off the midline was made into the coelomic cavity, using forceps or tweezers to pull the dermis and peritoneum away from internal organs to prevent injury to internal organs from the scalpel blade (Figure 11). The sterilized transmitter was inserted into the coelomic cavity (Figure 11) and the incision was closed with one or two interrupted sutures using sterilized absorbable suture material (PDSII, size 1). At the completion of tagging, the winter skate was allowed to recover prior to being released near the location of capture.

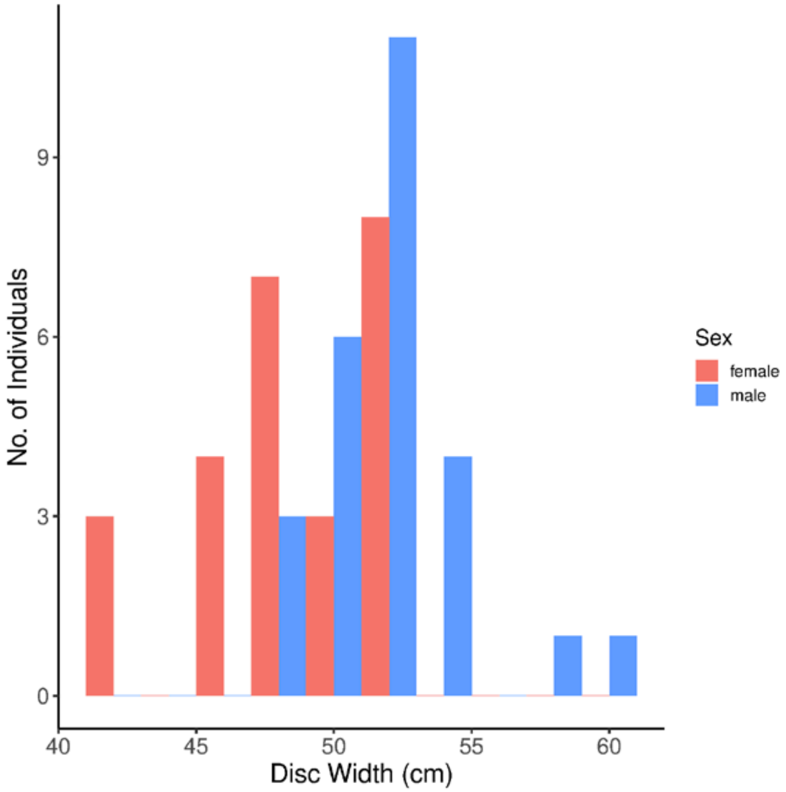


Figure 10. Length frequency for winter skate captured between 2 April 2017 and 7 May 2017. Bars are colored by the sex of the skate, as determined by presence or absence of claspers.

4 Methods - Seasonal Occurrence in DE WEA

Detections from the DE WEA acoustic receiver array were filtered to remove single detections (likely false detections). The data was also carefully reviewed visually to identify and remove spurious detections that were outliers based on the timing and location of detection for that species. To reduce autocorrelation in the dataset due to individual fish being detected on the same receiver multiple times in a row, detections were reduced to detections per individual per receiver per day (detection days, Breece et al. 2018). Analyses and data management were primarily done in R (R Core Team 2017).

Figure 11. Winter skate acoustic transmitter surgical implantation.
Left Photo: Tweezers were used to pull the dermal tissue of the Winter skate away from the delicate internal organs within. Right Photo: A VEMOCO V16-4H is inserted into the body cavity of a Winter skate.

4.1 Temporal Occurrence and Spatial Distribution

To identify potential areas of conflict- and times of the year when conflict with human uses of the DE WEA are more likely to occur, we summarized the temporal occurrence and spatial distribution of our focal species, as well as the other species detected by the receivers in the DE WEA. The temporal occurrence of all species detected on receivers in the DE WEA array was mapped, with station locations scaled to the number of cumulative detection days for that species over the two-year study. In addition, the presence and absence of all species detected throughout time was displayed on an abacus plot to show the seasonal occurrence of the identified species detected in the DE WEA array.

For our focal species, we also visualized the number of unique individuals recorded by any receiver in the DE WEA, broken down by month, as well as unique individuals on the “Northern Line”, “Eastern Line” and “Western Line”. Preliminary data exploration indicated that there were shifts in the regions of intensive use by Atlantic sturgeon and winter skate throughout the year, and in this way, we simplified the 25 arrays into three regions. This allows us to see the times of the year when there is the highest number of individual fish residing in or passing through the study area. Because the detection range of the receivers in the array did not overlap, there were gaps in the array meaning it was possible for fish to enter and exit the array without being detected. Having gaps in the array likely results in the underestimation of fish occurrence in the array, and therefore results presented are conservative estimates of occurrence and distribution.

4.2 Residency and Rate of Movement

While it is important to quantify the occurrence of our focal species in the array, and the seasonality of their occurrence, it is also important to understand their behavior while they occur in this region. Estimating the residency and rate of movement of these species will allow managers to have a better understanding of the impacts that the construction and presence of man-made structures like offshore wind turbines might have on these species. Animals with high residency may be more likely to be negatively affected than species quickly passing through.

Due to the shape of the array, we did not observe many Atlantic sturgeon making clear migratory movements through the DE WEA. Therefore, to aid in the calculation of residency and rates of movement in the Mid-Atlantic Offshore region, supplementary detections of Atlantic sturgeon tagged by our group were obtained from collaborators maintaining acoustic receivers deployed in the MD WEA (D. Secor and E. Rothermal). To understand the changes in behavior of Atlantic sturgeon detected in the DE WEA, we calculated periods of residency and movement using the R package *Vtrack* (Campbell et al. 2012). The *Vtrack* software package is specifically designed to qualify the behavior of animals detected using acoustic telemetry, and has been proven useful to classify the behavior of acoustically telemetered Atlantic sturgeon in the Mid-Atlantic ocean (Breece, Fox, and Oliver 2018; Ingram et al. 2019). For our analysis, we defined residence events for each individual sturgeon when they were detected at one receiver station for at least 12 hours (Breece, Fox, and Oliver 2018). A residence event was ended when 12 hours elapsed with no additional detections of the individual or if the individual was detected by another receiver. Movement events occurred in between times of residency and were filtered to be those that occurred in less than seven days to eliminate spurious detections between distant receiver stations across seasons. This is adequate time for an Atlantic sturgeon to transit the approximately 54 km from the southernmost extent of the MD WEA to the northernmost extent of the DE WEA based on published mean swimming speeds of 0.31 (SD= 0.20) m/s (54 km / 7 days = 0.089 m/s, (Ingram et al. 2019). A distance matrix was calculated for all receivers that detected an Atlantic sturgeon assuming a detection radius of 600 m (Kilfoil et al. 2017), from which we derived the rate of movement (ROM) during movement events between stations.

Detections of winter skate were too sparse (n = 609 detections) to include in this analysis. Although tagged winter skate were detected as near to shore as 3 miles and as far offshore as 25 miles within the MD WEA, the DE WEA and the NY WEA during this study, they were not detected in large numbers. While some of our tagged winter skate were detected in the MD WEA, *Vtrack* was unable to extract movement or residency behaviors and statistics due to limitations of the dataset, therefore we are unable to determine potential transit rates for this species through our study region at this time.

4.3 Environmentally Driven Predictive Model

Defining species distribution models for Atlantic sturgeon is challenging because of their complex interactions between marine and riverine ecosystems and physical forcings. While the location of sediment and benthic structure is relatively stable over ecological time, ocean variables that affect Atlantic sturgeon such as temperature, salinity, and turbidity are forced over shorter time scales. These factors may also influence behavior (residency vs. movement) and population parameters (e.g. growth and fecundity) as adult and large juvenile Atlantic sturgeon are thought to forage extensively in the marine and estuarine environment (Stein et al. 2004). Understanding environmental parameters (static and dynamic) that are associated with Atlantic sturgeon occurrence on daily and seasonal time scales, gives managers a tool to predict when and where Atlantic sturgeon will occur, when more direct observations are not feasible.

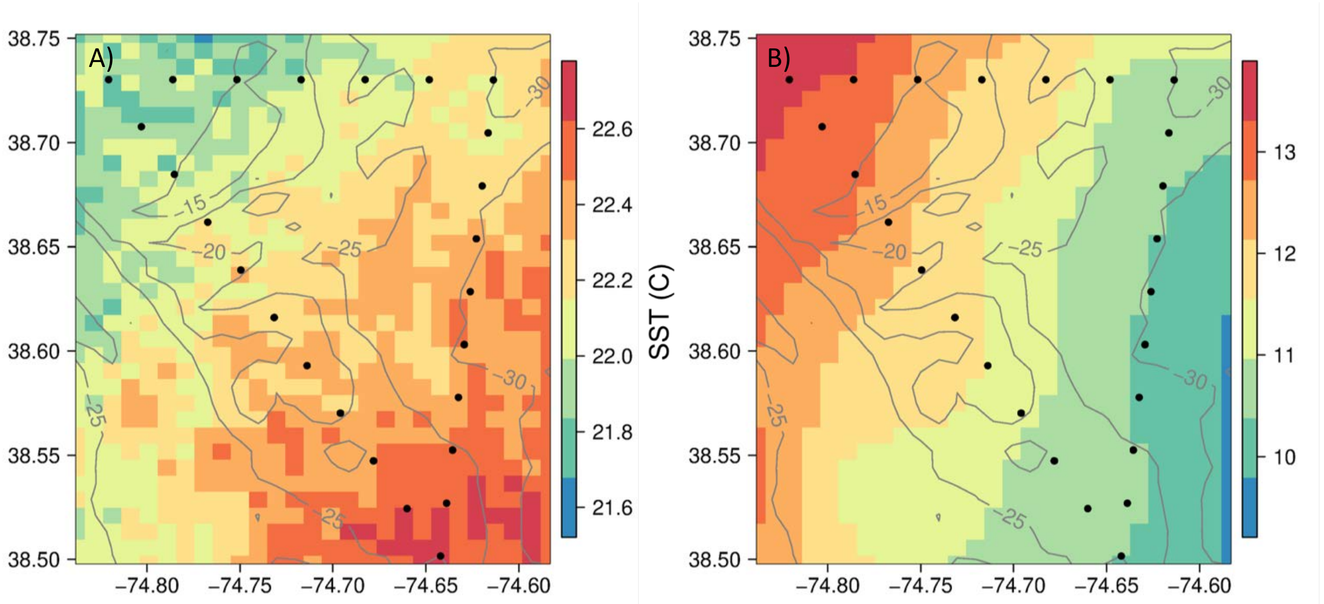


Figure 12. Climatology of SST and modeled bottom temperature for July 3-11 in the DE WEA. Panel A) Sea surface temperature from the MODIS-Aqua satellite platform. Panel B) Modeled bottom temperature from the DOPPIO ROMS model (Rutgers University).

To determine the associations between Atlantic sturgeon and environmental parameters, potential predictor variables were extracted for each day and station location during the two-year study. Static variables included water depth (Figure 2A; NOAA National Centers for Environmental Information, US Coastal Relief Model), modeled bottom type (sediment type, Wentworth Classification, Figure 2B, Guida et al. 2017), and terrain metrics (slope, aspect, rugosity, Guida et al. 2017). Dynamic variables included one day composites of remotely sensed sea surface variables from the NASA MODIS-Aqua satellite platform. These variables included sea surface temperature (SST, Figure 12A), and 12 ocean color absorption channels (available at http://tds.maracoos.org/thredds/MODIS.html and http://basin.ceoe.udel.edu/thredds/catalog.html). Ocean color has been shown to be useful for predicting Atlantic sturgeon (Breece et al. 2018) and Sand Tiger shark (Haulsee et al. 2018) occurrence in the Mid-Atlantic Bight, and is likely a proxy for ocean productivity, nutrient fields, river plumes or other water masses that drive oceanic species occurrence. In addition, because Atlantic sturgeon are a benthic associated fish, we also extracted modeled daily bottom temperatures for each receiver station from the Experimental System for Predicting Shelf and Slope Optics ROMS model (ESPreSSO, available between 23 Feb 2017 to 31 Oct 2017, http://www.myroms.org/espresso/) and DOPPIO ROMS model (Figure 12B; available between 1 Nov 2017 to 27 Feb 2019, http://tds.marine.rutgers.edu/thredds/catalog/roms/doppio/2017_da/avg/catalog.html?dataset=roms/doppio/2017_da/avg/Averages_Best). These environmental conditions were then matched to Atlantic sturgeon presence (detection days per individual) and absences. Absence records were created by extracting receivers where individual Atlantic sturgeon were not detected between the time of first detection and last detection of each individual on the receiver array, and accounting for when receivers were deployed (Breece et al. 2018; Haulsee et al. 2018). Presence and absence records for all identified Atlantic sturgeon detected in the DE WEA were used for this analysis, including those individuals tagged by other research groups. This increased our sample size of Atlantic sturgeon from 123 to 360 and greatly improved the strength of our modeling analysis.

The goal of predictive species distribution modeling is to determine the fewest predictor variables that contain the most information about the response variable, in this case the binomial presence and absence of Atlantic sturgeon. Therefore, variable reduction techniques were used to eliminate predictor variables that were highly correlated ($|r| > 0.7$) and contained the highest information values (R package *InformationValue*, (Prabhakaran 2016).

Generalized additive models (Hastie and Tibshirani 1990) were used to quantify the non-linear relationships between the binomial presence/absence of Atlantic sturgeon and environmental predictor variables using the *mgcv* package in R (Wood 2011). Thin plate shrinkage smoothers (ts) were used to fit the complex relationships between predictors and the response and shrink non-significant variables out of the model, with tensor product (te) smoothers used to test interactions (Wood 2003). Models were systematically tested in a forward stepwise selection protocol, and model performance was evaluated by the reduction of Akaike’s Information Criterion (AIC) and increasing deviance explained (Wood 2006). The least complex model, with the lowest AIC was chosen as the “best” model. Models were cross validated by systematically removing 20% of the training data, building the model on the remaining 80% of the data and comparing those predictions to the reserved 20%. The cross-validation process calculated model performance statistics, explained deviance (r^2), sensitivity (presences correctly predicted), specificity (absences correctly predicted), optimal threshold (predicted prevalence where sensitivity equals specificity), percent correctly classified (PCC), and the area under the receiver operating curve (AUC), using the ‘Presence Absence’ package in R (Freeman and Moisen 2008).

Model predictions were visualized using environmental variable layers interpolated to the same resolution as the lowest resolution input variables, the remotely sensed environmental variables (4 km^2 resolution). For dynamic environmental variables (SST, ocean color, and bottom temperature), monthly climatologies were used as inputs to create probability of occurrence maps.

Detections of winter skate were too sparse to create a dynamic habitat model for this species in this region, but we were able to use simple habitat preference associations to characterize preliminary information about their occurrence and distribution as mentioned below.

During the complex GAM model building process, it became apparent that there were strong associations between Atlantic sturgeon and sediment type. The Wentworth sediment type associated with the presence and absence of both species at receiver stations was converted into a categorical variable using the established ranges of ϕ (Appendix A.1.1., Hobson 1979). A simple habitat selection analysis for Atlantic sturgeon and winter skate was performed to test for selection of certain sediment types. A chi-squared goodness of fit test was used to determine if the proportion of sediment types associated with detections of Atlantic sturgeon and winter skate (“used”) was significantly different from the proportion of sediment types available.

5 Results - Recovery Efficiency of Standard vs. Acoustic Release Receiver

Throughout the two-year study, six acoustic receivers were lost despite our efforts to prevent gear loss (Table 2). We attempted to prevent gear loss in two ways: 1) We consulted with a professional pot fisherman, Captain Wes Townsend, who has decades of experience fishing seabass and lobster pots in this region. His livelihood depends on the reliability of this mooring designs, and he made every effort to assist us in designing and setting our gear to with the local conditions in mind, to prevent equipment loss. 2) Regular maintenance, as weather permitted, allowed us to untangle gear after storms, replace missing surface floats, and replace anchors and blocks as needed to ensure we would be able to locate gear upon successive maintenance trips. Despite these preventative measures, we lost six VR2Ws during the study (Table 2). We did not lose any acoustic release receivers, likely because they did not have any surface expression floats and lines in the water (Table 2).

For five of the traditional VR2W receivers, the entire mooring was not able to be located visually (unable to locate surface floats or see mooring underwater using the vessels echosounder), or with a grapple. For one of the receivers, the mooring was recovered, but the receiver was sheared off of the mooring (zip-tie attachments were broken). One station (BOEM_E_15) was lost twice. This station is located in the lower corner of the array, where large tankers and shipping vessels often anchor or transit through the study area before entering the nearby shipping lanes (Figure 13). After the second loss at the same station, and our assumption that shipping traffic was likely responsible for these losses, we converted the station to a bottom anchored VR2AR acoustic release receiver station, which prevented future station losses.

These losses not only represent monetary losses equivalent to the cost of the receivers and mooring gear but also in the loss of the valuable data that was archived on the equipment (Table 2).

Table 2. Summary of VEMCO acoustic receivers lost during study.
Losses were likely due to interactions with fishing activities, shipping activities or weather. Stations highlighted in italics were lost after the cut-off date of our study (23 Feb 2019), so losses in data did not impact data analyses. In addition, it is possible these stations may still be recoverable.

Lost Receiver	Type	Station	Last Downloaded	Date Discovered Lost	Days Data Lost	Replaced?
VR2W-119810	Traditional	BOEM_E_15	4/18/17	6/26/17	69	Yes
VR2W-121270	Traditional	BOEM_W_21	4/18/17	6/26/17	69	Yes
VR2W-132378	Traditional	BOEM_E_15b	11/28/17	1/26/18	59	Yes
VR2W-114877	Traditional	BOEM_E_13	1/26/18	5/5/18	99	Yes
VR2W-110645	*Traditional*	*BOEM_E_08*	*2/23/19*	*6/1/19*	*98*	*No*
VR2W-107904	*Traditional*	*BOEM_N_05*	*2/23/19*	*6/1/19*	*98*	*No*

5.1 Interaction with Acoustic Seafloor Survey Vessel

We were concerned that the acoustic survey to classify bottom type, performed by contractors hired by Deepwater Wind/Orsted (http://dwwind.com/press/deepwater-wind-accelerates-skipjack-wind-farm-multi-million-dollar-ocean-floor-survey/), would interfere with the ability of the receivers to detect acoustic tags. The VEMCO VR2AR receivers have the ability of measuring ambient noise at 69 kHz to measure how much noise interference (from sea state, turbidity, rainfall, air bubbles, boat traffic, depth sounders, construction, biological (i.e. snapping shrimp), etc.) may be interfering with the ability of the

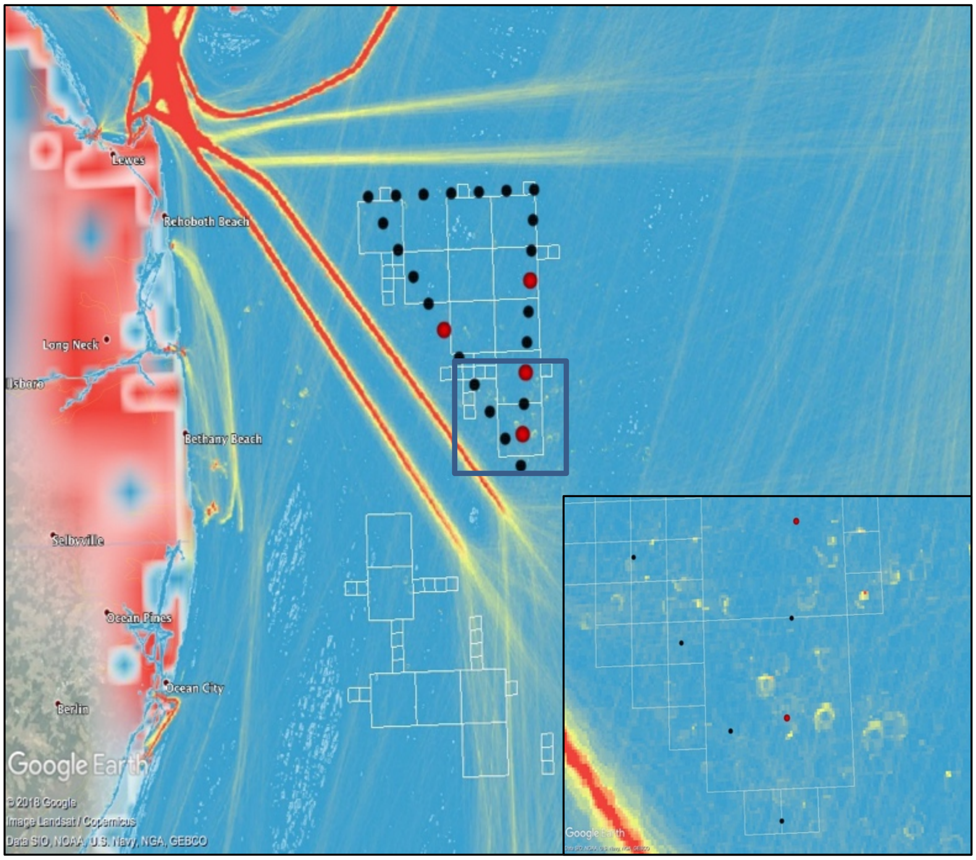


Figure 13. Map of DE WEA VEMCO acoustic receiver array compared to vessel traffic. Red points indicate receiver stations where a standard VR2W receiver with surface expression was lost between Feb 2017 and Mar 2019. Example concentration of vessel traffic (2011) indicated by colors, with cool colors indicating low concentration and warm colors indicating high concentration (https://coast.noaa.gov/arcgis/rest/services/MarineCadastre/2011VesselDensity/MapServer). Inset shows heavy anchorage used by large shipping vessels waiting offshore before using shipping lane to enter DE Bay. Note the circular patterns in concentration due to ships swinging on their anchors as the tide changes.

receivers to detect acoustic transmitters in fish. Comparing the pattern of the cumulative number of detections over the study, and the peak noise levels measured by the acoustic release receivers in the array, there does not appear to be any obvious gap in transmitter detections that correlates with increasing ambient noise (Figure 14A). Highest average noise was recorded between mid-September and early-October at stations BOEM_W_21, BOEM_W_19, BOEM_W_17, BOEM_W_18, and BOEM_E_14 (Figure 14B). These receivers are concentrated in the lower corner of the DE WEA, where the proposed wind turbines for the Skipjack Wind Farm will be located (https://orsted.com/en/Our-business/Offshore-wind/Our-offshore-wind-farms). While we believe our receivers did record increases in ambient noise levels during the survey, it is unclear whether the ability of the receivers to detect tagged animals was affected, or if there were any changes in animal behavior as a result.

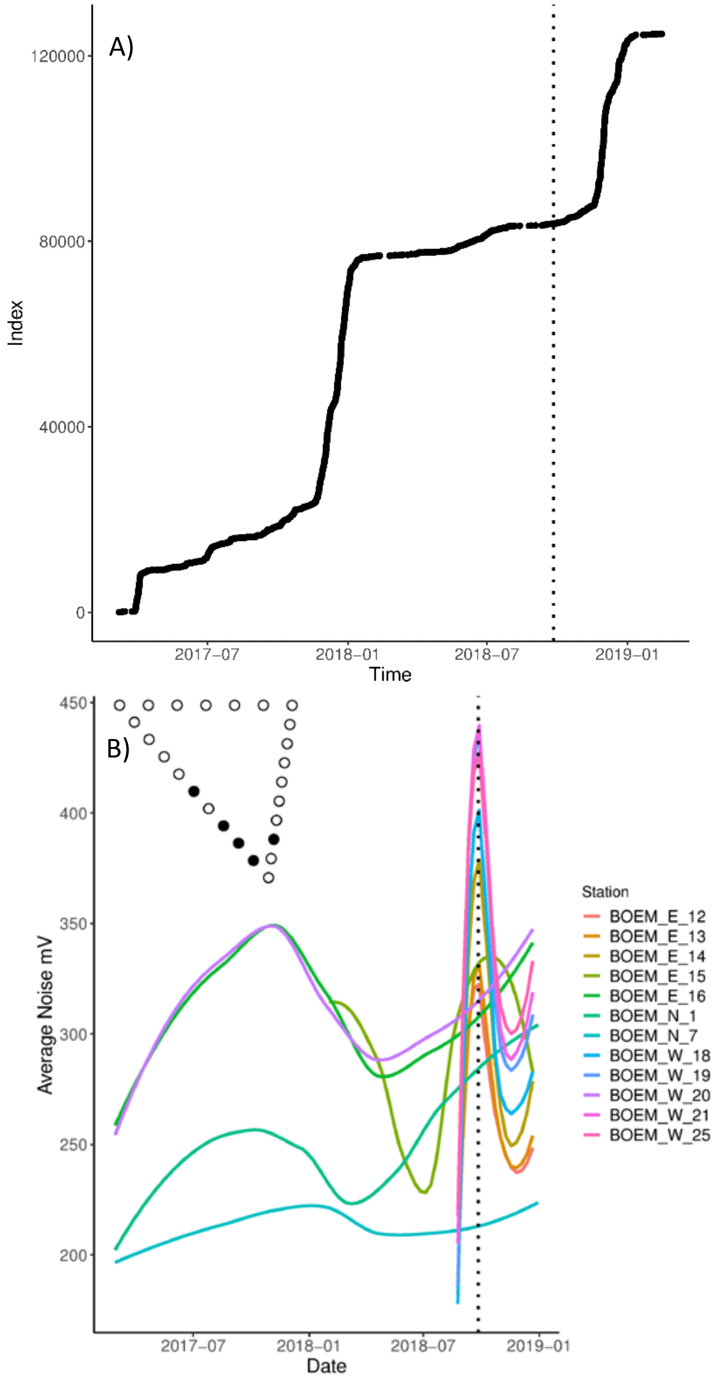


Figure 14. Accumulation of acoustic detections over time compared to peaks in ambient noise level in DE WEA.

Panel A) Cumulative acoustic detections from all species and all stations in the DE WEA VEMCO receiver array between deployment 27 Feb 2017 and recovery 23 Feb 2019. Panel B) Recorded average noise level (at 69 kHz) from VR2AR receivers between deployment 27 Feb 2017 and recovery 23 Feb 2019. Black vertical lines on both graphs represent peak noise levels, 26 Sept 2018. Black dots in receiver array map inset represent stations where peak average noise levels were recorded.

6 Species Occurrence and Distribution

With two years of data, we were able to see trends in the seasonal pattern of spatial distribution of all species in the array. The array was frequented by multiple different species, including our focal species, which varied in the region of the array where they occurred, and in how much time they spent in the area.

6.1 Atlantic Sturgeon

Between 23 Feb 2017 and 27 Feb 2019, receivers in the DE WEA recorded 43,620 detections of 360 individual Atlantic sturgeon. These Atlantic sturgeon were originally tagged by 11 different primary researchers and included 32 (out of 50) individuals tagged for this study.

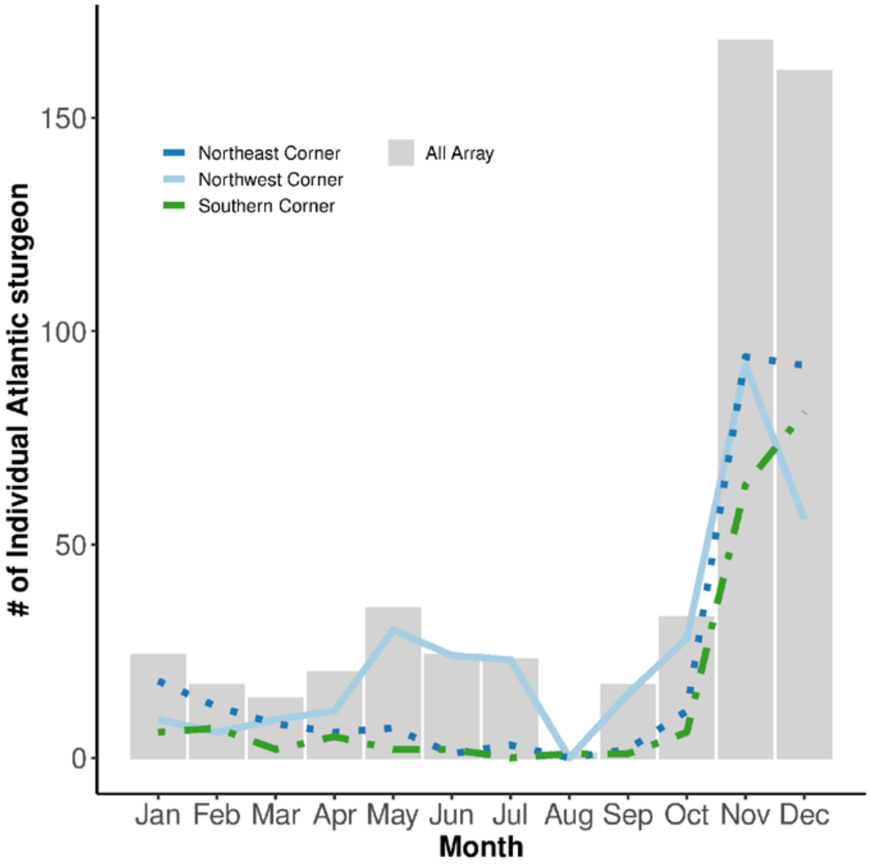


Figure 15. Individual Atlantic sturgeon occurrences by month and region of the DE WEA. Grey bars show the number of unique individual Atlantic sturgeon detected in the DE WEA observed over the two-year study. Colored lines represent the region (corner) of the array where these individual fish were detected.

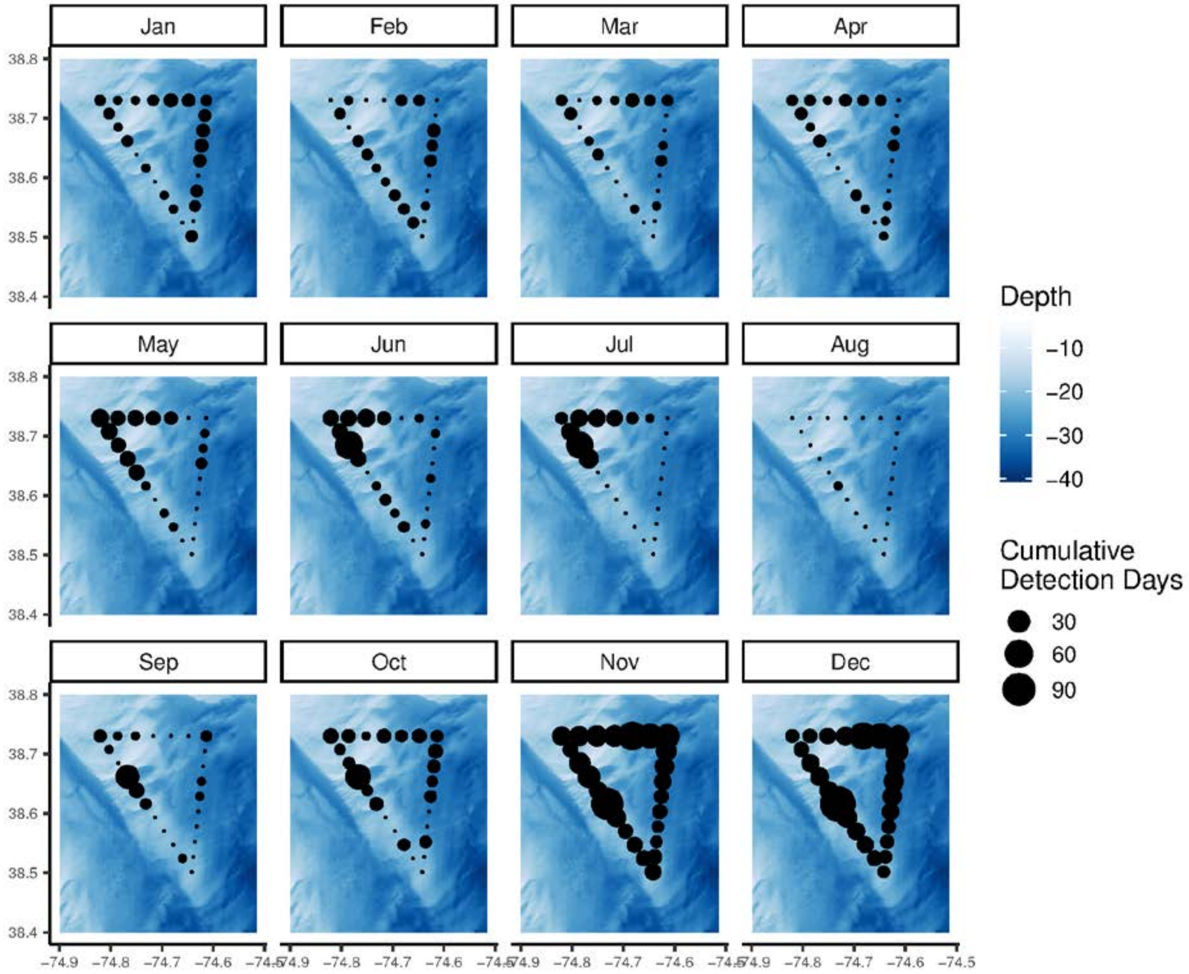


Figure 16. Spatial distribution of detections of Atlantic sturgeon on receivers of the DE WEA broken down by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all Atlantic sturgeon recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

Atlantic sturgeon were detected during all months of the year in the DE WEA; however their occurrence is lowest in August, and highest in November and December (Figure 15). More Atlantic sturgeon occur in the northern corners (northeast and northwest) throughout the year, however the number of unique Atlantic sturgeon recorded increases in all three corners in November and December (Figure 15). A smaller peak in the number of individual Atlantic sturgeon recorded occurs between April and May, where Atlantic sturgeon occur in the northwest corner (Figure 15). These patterns of occurrence are shown in more detail in Figure 16. Specific receiver stations near the center of the gate of receivers that runs from the northwest to southern corner accumulated many more detection days than other receivers consistently throughout the year (Figure 16).

6.2 Winter Skate

Winter skate occurrence was low throughout the two-year study. In total, receivers in the DE WEA recorded 609 detections of 13 winter skate. These fish were all tagged as a part of this study. Similar to Atlantic sturgeon, peaks in winter skate occurrence occurred between March and May, and again in November and December, when considering the diversity of individual winter skate detected in the DE WEA (Figure 17). These individuals occur most frequently near receivers in the northwest corner during both peaks, with the southern corner again detecting the fewest number of individuals (Figure 17). These patterns are also apparent when observing the accumulation of detection days for Winter skate on individual receivers in the DE WEA, with most detections occurring on only a few receivers in the northwest corner (Figure 18).

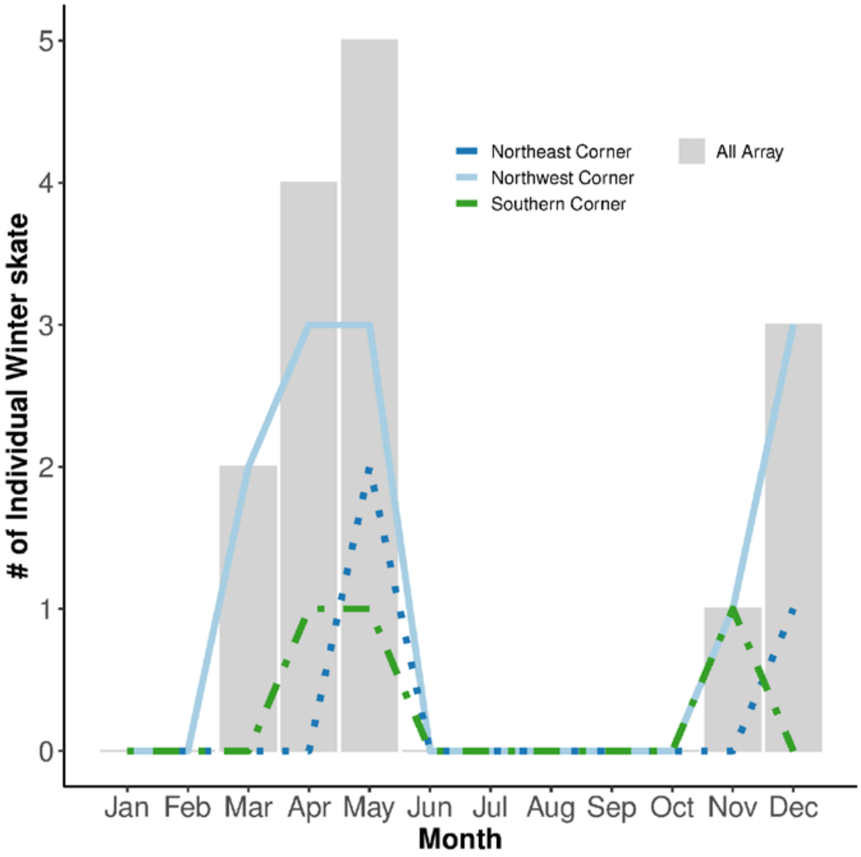


Figure 17. Individual winter skate occurrences by month and region of the DE WEA. Grey bars show the number of unique individual winter skate detected in the DE WEA observed over the two-year study. Colored lines represent the region (corner) of the array where these individual fish were detected.

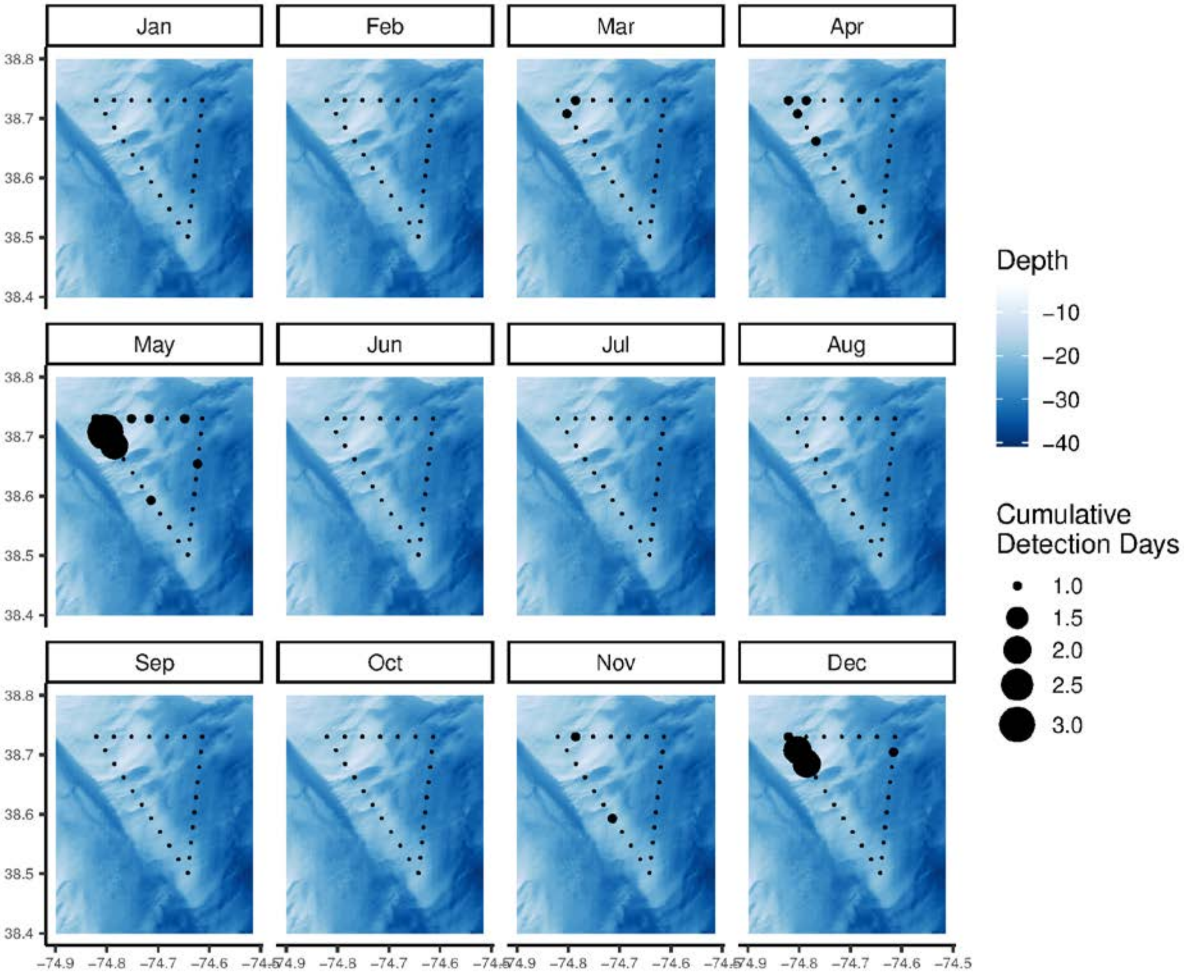


Figure 18. Spatial distribution of detections of winter skate on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all winter skate recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

6.3 All Other Species

In addition to Atlantic sturgeon and winter skate, the receivers deployed in the DE WEA detected acoustic transmitters associated with 28 additional species (Figure 19). While we detected a large number (n=360) unique Atlantic sturgeon, one of our focal species, we also detected a very large number of striped bass (n=320, Figure 19). Over the two-year study, receivers logged 124,710 detections, which were often seasonal in nature (Figure 20). As discussed above, Atlantic sturgeon occurred almost all year round, however species such as striped bass and multiple species of sharks (white shark, dusky shark, blacktip shark) occurred on seasonal cycles (Figure 20, Appendix B). Striped bass occurred most frequently in the winter and spring, likely during times of migration along the East Coast (Figure 20). In contrast, elasmobranchs occurred most frequently in the summer months (Figure 20).

The highest numbers of unique individual animals carrying acoustic transmitters were detected in November and December (Figure 21). Between 300-400 unique animals occurred in the DE WEA in November and December throughout the study period (Figure 21). During these months, more individuals occur in the northern corners than the southern corner (Figure 21). However, during a secondary peak in number of animals observed in April, more individuals were recorded in the southern corner.

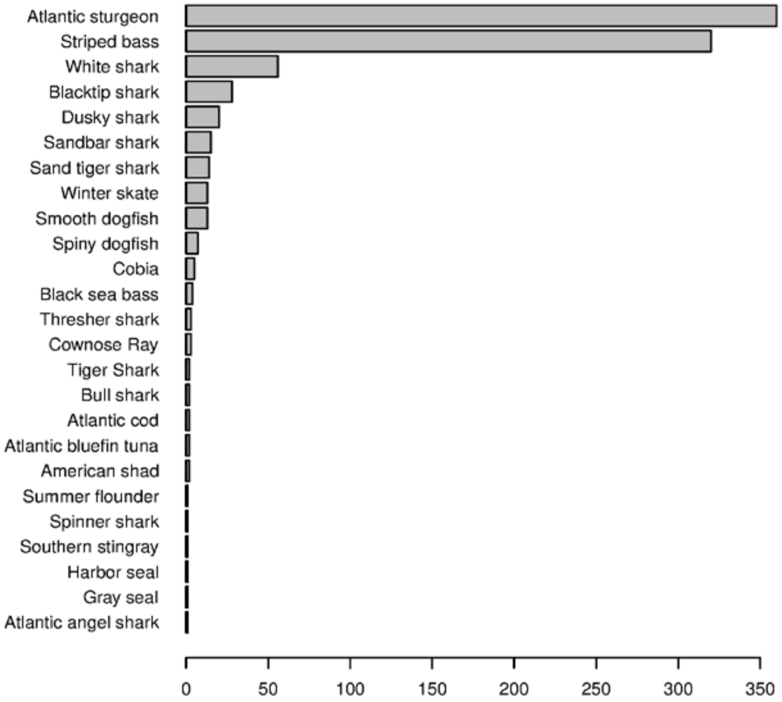


Figure 19. Number of tagged individuals detected
Colored points represent the presence of at least one tagged individual for 30 species detected in the DE WEA.

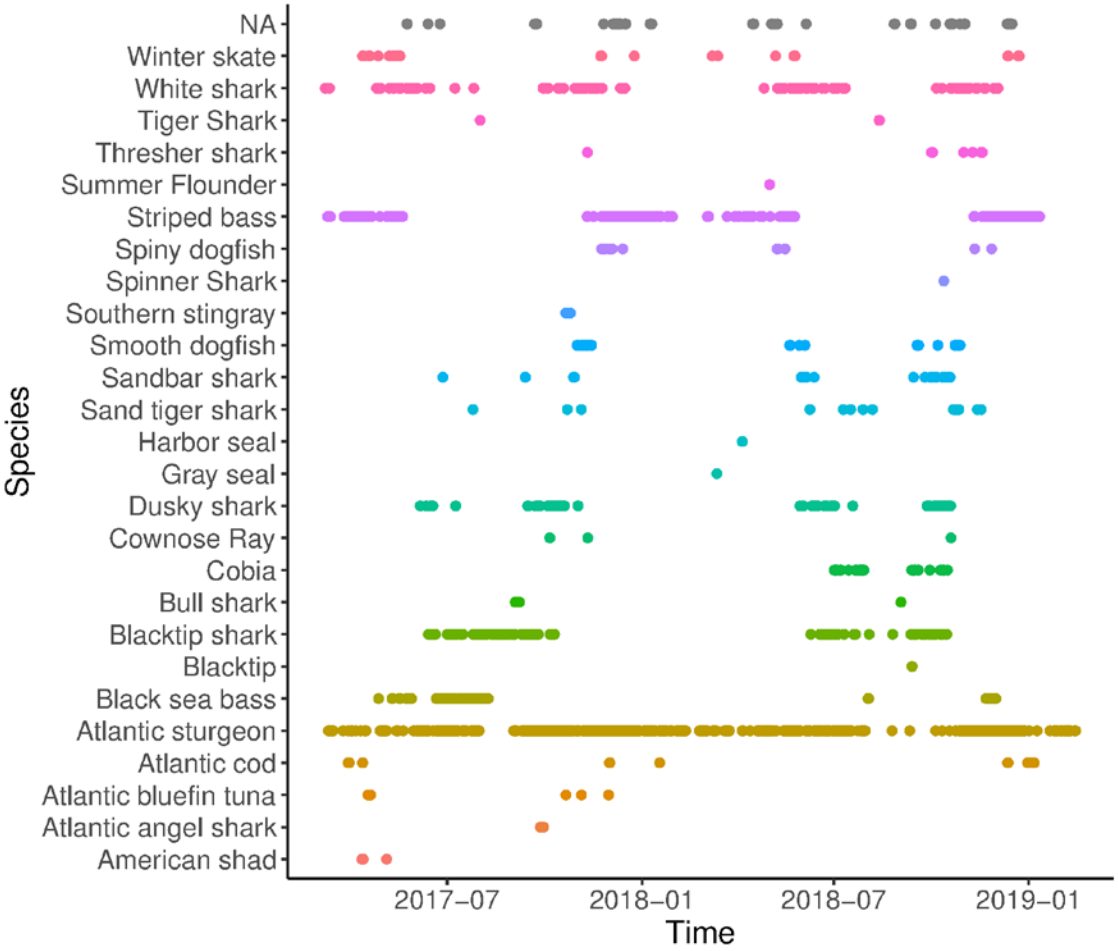


Figure 20. Occurrences of all species detected in the DE WEA throughout time.
Colored points represent the presence of at least one tagged individual for 30 species detected in the DE WEA.

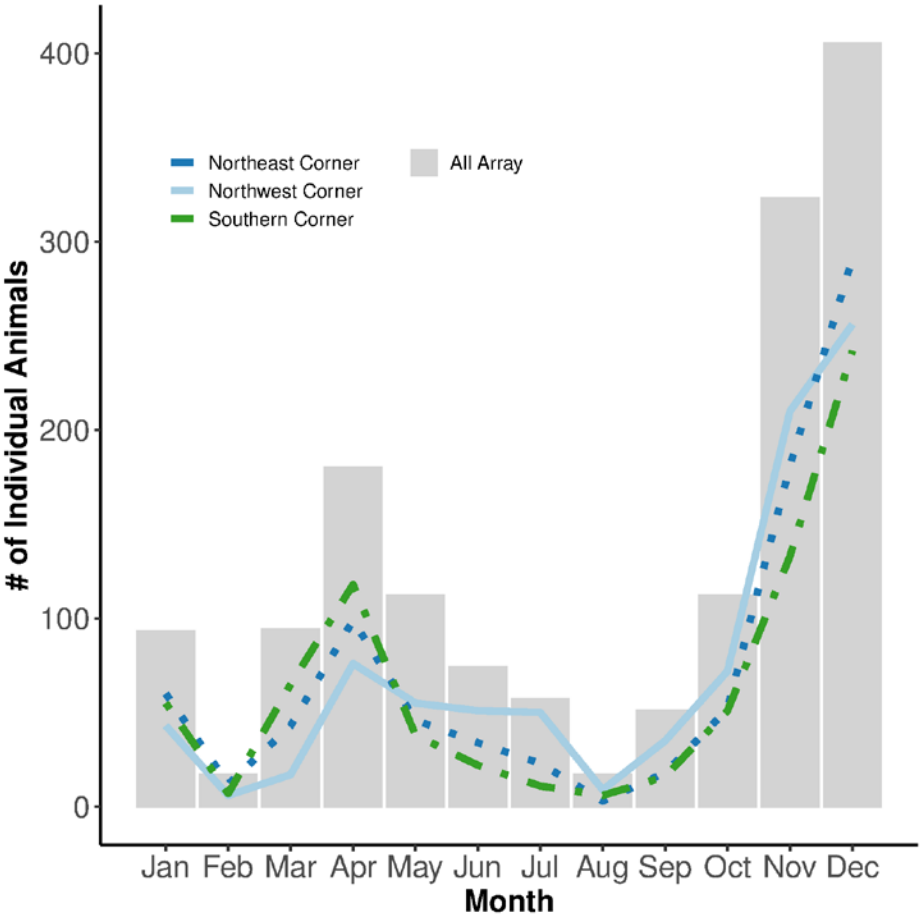


Figure 21. Individual occurrences by month and region of the DE WEA.
Grey bars show the number of unique individuals detected in the DE WEA observed over the two-year study. Colored lines represent which region (corner) of the array these individual fish were detected occurring.

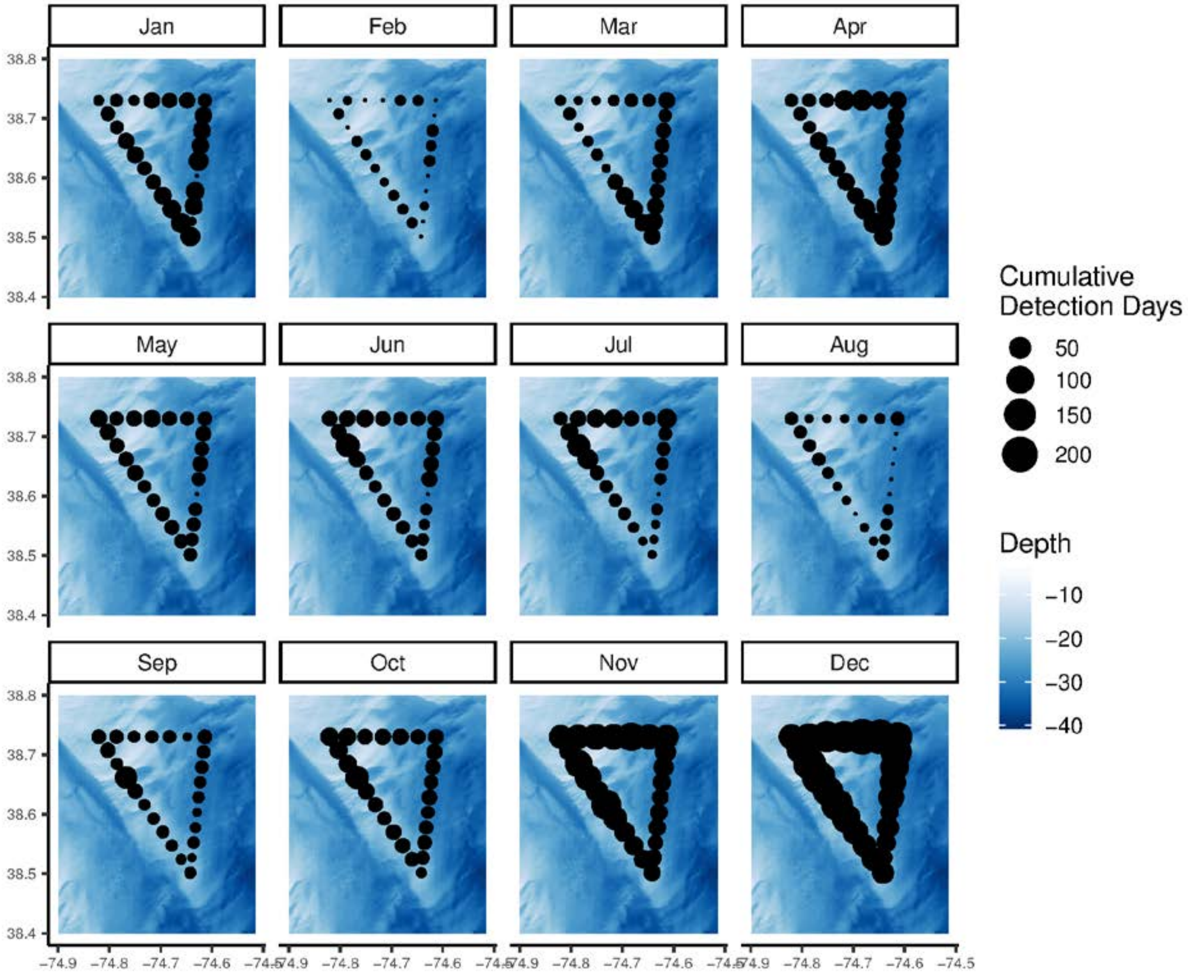


Figure 22. Spatial distribution of detections of all species on receivers of the DE WEA broken down by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all species recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

Plotting detection days on receiver stations by month for all species emphasizes the heavy use of all of the acoustic receivers in the DE WEA during January, November and December (Figure 22). In fact, for the majority of the year, detections of at least one species were recorded on all receiver stations, with the exception of February and August during which the fewest number of individuals were detected for the fewest numbers of detection days (Figures 20-22). The summarized occurrences for all species detected are shown in Appendix B.

7 Atlantic Sturgeon Residency and Rate of Movement

Due to the high number of individual Atlantic sturgeon detected in the DE WEA, we were able to use established analytical techniques to describe residency and non-residency behaviors exhibited by Atlantic sturgeon. Residency events are seasonal, and generally short in duration.

7.1 Residency

Using the software package *VTrack*, residency events were identified between 12.01 hrs and 29 days (Figure 23). Residency events were centered around July and November-December during both years of the study (Figure 22). The longest residency events occurred in December 2017 and December 2019 (15 days and 29 days respectively (Figure 23). The longest residency event (29 days) was for Atlantic sturgeon with transmitter code A69-9001-17245. This fish was tagged by Carter Watterson from the U.S. Navy in the Chesapeake Bay in September 2017. In December of 2018, this fish was detected by station BOEM_N_7 for multiple weeks before being detected by 5 other stations in the array and eventually leaving (Figure 23 inset). This fish was then detected again in July of 2019 (Figure 23 inset), further confirming that this residency event was not the result of a mortality, or an expelled transmitter from the fish.

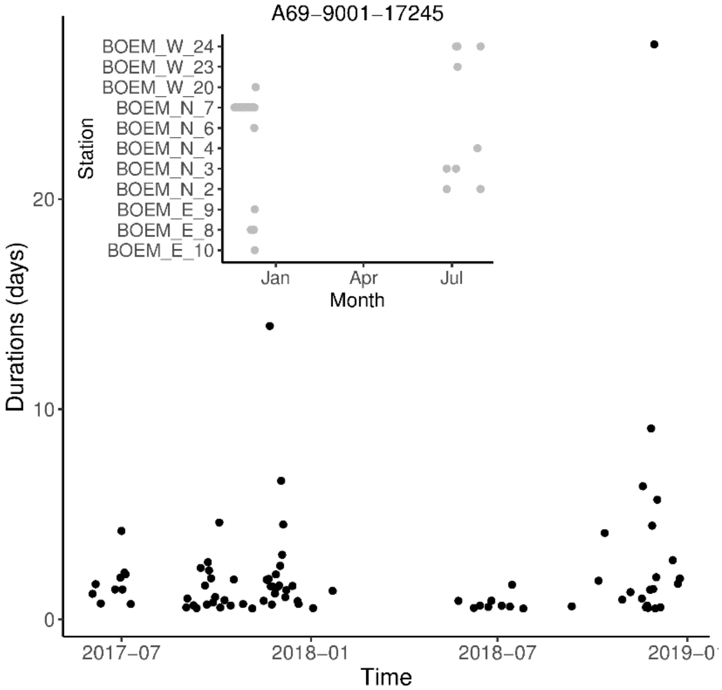


Figure 23. Duration of residency events for Atlantic sturgeon in the DE WEA over time.
The duration of residency events calculated by Vtrack for Atlantic sturgeon detected in the DE WEA. Inset shows the supplementary detection at station information for Atlantic sturgeon A69-9001-17425, which exhibited the longest residency event (29 days) in December 2018.

7.2 Non-Residency

Periods between residency events were classified as non-residency events in *VTrack*. During these times we assume Atlantic sturgeon are transiting between sites and we used these movements to calculate transit rates within the DE WEA (movements between receivers in the array), and between the DE WEA and the MD WEA (for Atlantic sturgeon tagged only by Dr. Dewayne Fox). The density distribution of transit rates are similar for Atlantic sturgeon movements within the DE WEA and between the DE WEA and MD WEA, however there is a slight shift in the distribution to faster transit rates for fish moving between the DE WEA and MD WEA compared to fish only transiting within the DE WEA (Figure 24). Calculated transit rates were between 0.003 and 1.480 m/s, with an average transit rate of 0.284 m/s (Figure 24). There are slight seasonal patterns where transit events occurred, with movements within the MD WEA only occurring more often in November-December, and transit events within the DE WEA occurring in July and January (Figure 25). When fish moved between the DE WEA and MD WEA, we were able to calculate an approximate direction of movement (Figure 26). Most transits of this type were for Atlantic sturgeon swimming south from the DE WEA to the MD WEA during December, although there are northerly movements during this period as well (Figure 26). The few observations of transits between the two WEAs that occurred in the late spring were fish swimming north, however this behavior is less commonly observed (Figure 26). The distribution of transit speeds does not appear to change depending on the direction of travel (Figure 26), however, it is possible we did not detect the majority of the population when they were transiting north in the spring based on model observations produced by Breece et al (2018), which observed Atlantic sturgeon migrating closer to shore in the spring compared to the fall.

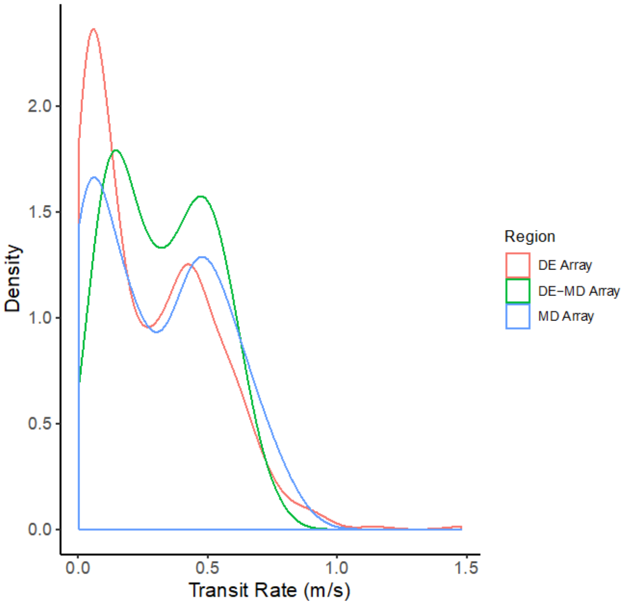


Figure 24. Calculated transit rates for Atlantic sturgeon in Mid-Atlantic WEAs.
Transit rates for Atlantic sturgeon moving within the DE WEA and between the DE WEA and the MD WEA calculated for the non-residency event output from *VTrack*.

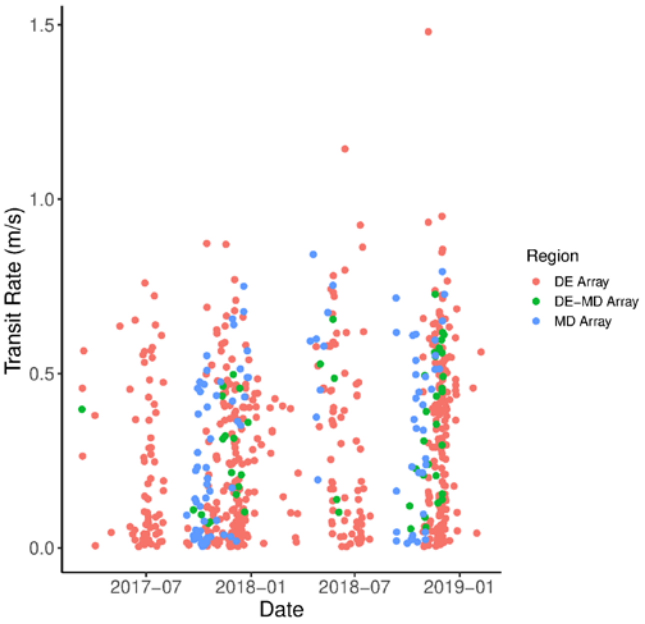


Figure 25. Time series of calculated transit rates for Atlantic sturgeon in Mid-Atlantic WEAs. Transit rates for Atlantic sturgeon moving within the DE WEA and between the DE WEA and the MD WEA calculated for the non-residency event output from VTrack over time.

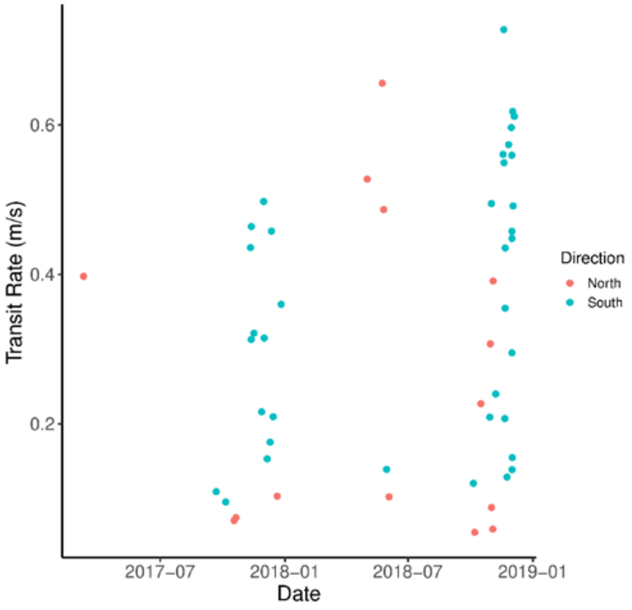


Figure 26. Calculated transit rates for Atlantic sturgeon in Mid-Atlantic WEAs. Transit rates for Atlantic sturgeon moving within the DE WEA and between the DE WEA and the MD WEA calculated for the non-residency event output from VTrack.

8 Predictive Habitat Models

Predictive habitat models were created for our focal species using two different methods. A simple bottom type habitat selection analysis tested for associations for certain bottom types by Atlantic sturgeon and winter skate. The high number of detections of Atlantic sturgeon also allowed us to use generalized additive models to model the complex associations between sturgeon and environmental predictors.

8.1 Association with Bottom Type

Using the Wentworth grain size scale (Appendix A.1.1.) to classify the modeled sediment type output into categories, presences and absences of Atlantic sturgeon and winter skate were matched to three sediment types; very coarse sand, coarse sand and medium sand (in decreasing grain size order). Comparing sediment types at each receiver station used, versus the sediment types at each receiver station that were available, we were able to see that Atlantic sturgeon and winter skate are selecting for different sediment types (Figure 27). The proportion of sediment types used by Atlantic sturgeon, compared to what was available, was significantly different (Figure 24A, $X^2 = 115.82$, df = 2, p-value < 0.0001). This relationship was driven by a preference for coarse sand, and the slight avoidance of very coarse sand and strong avoidance of medium sand (Figure 25A). In contrast, Winter skate were observed using sediment

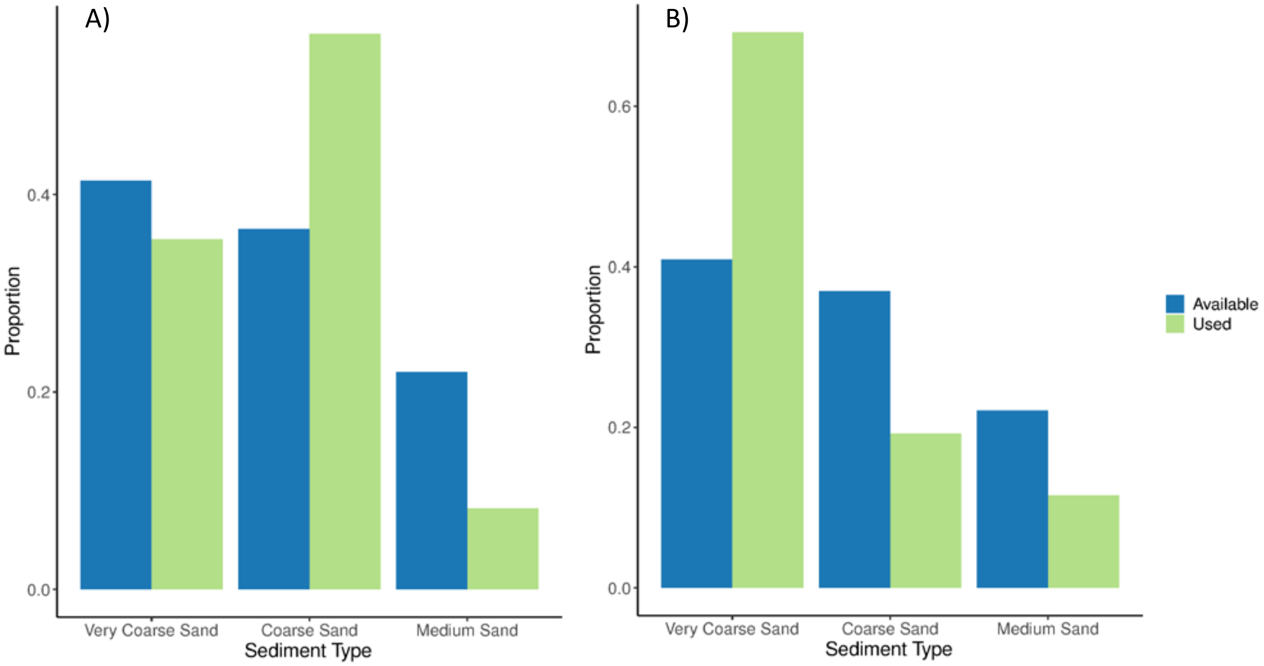


Figure 27. Associations between Atlantic sturgeon and Winter skates and sediment types observed in DE WEA.
Proportion of sediment types used vs. available for A) Atlantic sturgeon and B) Winter skate. Sediment types were those observed nearest to the acoustic receiver station, and were categorized from the modeled Wentworth sediment grain size output provided by (Guida et al. 2017).

types differently than Atlantic sturgeon (Figure 24B, $X^2 = 5.1597$, df = 2, p-value = 0.075), preferring coarse sand and avoiding coarse sand and medium sand. At this time, we are unable to determine the biological significance of these sediment type preferences for each species, but it is likely that these sediment types may be related to food availability (both species are benthic feeders), or related to preferences for local benthic and oceanographic features such as the occurrence of strong tidal currents moving through a channel. Further research is needed to understand if these sediment types are biologically important, or spuriously correlated.

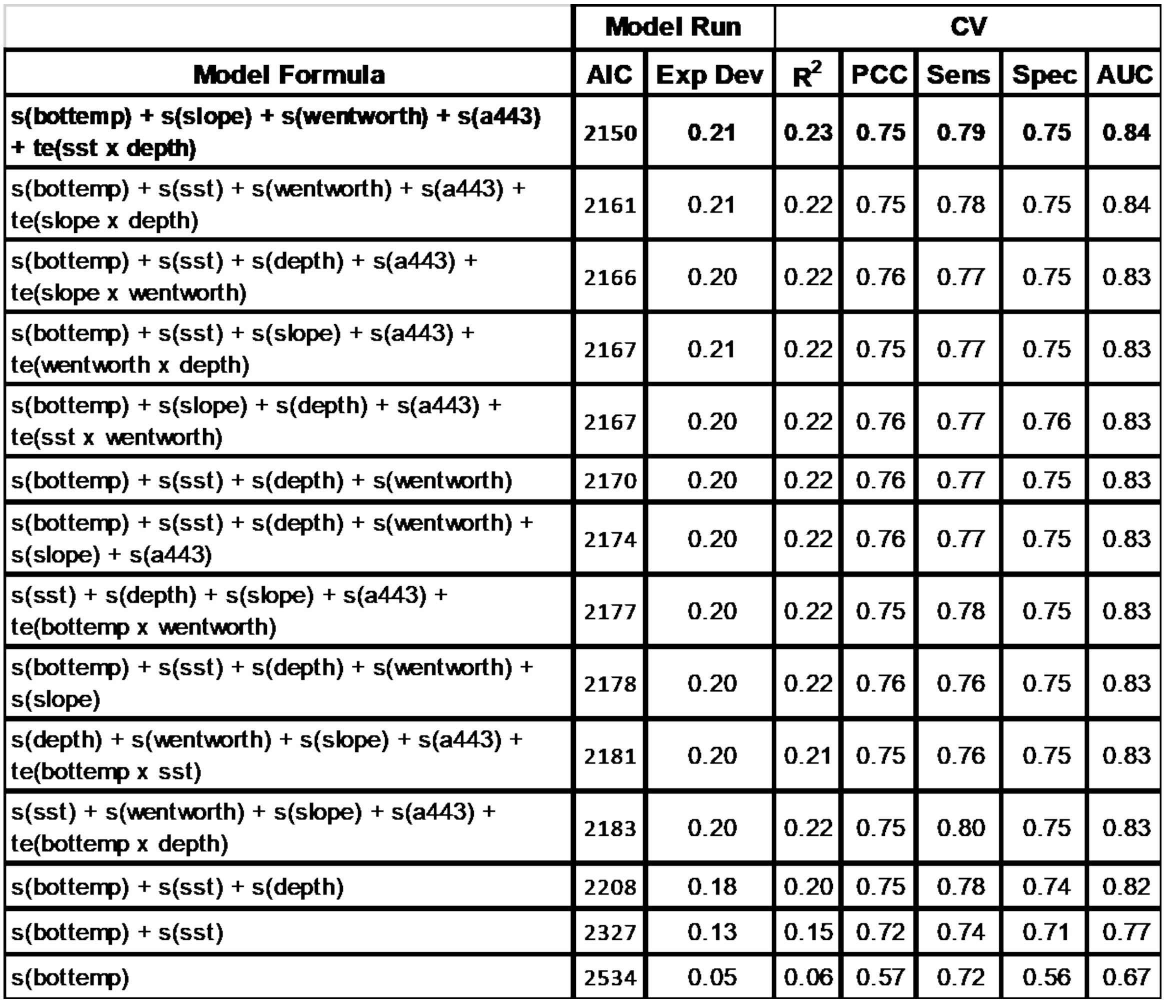
8.2 GAM Selection and Performance

Generalized additive models were tested for Atlantic sturgeon detected in the DE WEA only. Models were built in a forward-selection method and evaluated using cross-validation and reduction in AIC techniques. Based on the pairwise correlation between predictor variables and information values, we determined that bottom temperature, depth, Wentworth sediment type, sea surface temperature (SST), absorption at 443 nm (a443; sr^{-1}) and 555 nm (a555; sr^{-1}), and bottom slope were likely predictive of Atlantic sturgeon presence and absence. Ocean color absorption at 443 nm (blue) and 555 nm (green) are related to variables used to estimate chlorophyll concentrations in the surface ocean. The relationship between these variables and Atlantic sturgeon is likely correlated to the preference for different water types (coastal, productive, terrigenous in origin etc.) that has been documented in the literature (Breece et al. 2018). Day of year is also highly related to Atlantic sturgeon occurrence but is highly correlated with bottom temperature. We therefore used bottom temperature as a variable that is more ecologically interpretable because it is thought that Atlantic sturgeon spend most of their time near the seafloor (Erickson et al. 2011). Models were built using combinations of these predictors, as well as interactions between pairs of predictors. For all models tested, a555 was not a significant contributor to the model, and the effective degrees of freedom were smoothed to zero, effectively removing that variable from each model, therefore this predictor is not shown in the model results. The best performing model included the additive effects of bottom temperature, Wentworth sediment type, bottom slope, a443 and the interaction of depth and SST (Table 3). Variable importance This model was the least complex model tested that had the lowest AIC and highest explained deviance (Table 3). Cross-validation analysis revealed that this model captures about 1% of the deviance of Atlantic sturgeon occurrence, correctly classifying 79% of sturgeon presences (sensitivity), and 75% of absences (specificity, Table 3). The AUC was high (0.84), indicating that the model predicts sturgeon occurrence much better than random (AUC=0.5, Table 3).

In terms of contribution to the model, water temperature (bottom and surface) were most important, followed by bottom characteristics (depth, sediment grain size, bottom slope), and a443 (Figure 28). Partial variable effect plots show the complex relationships between the occurrence of Atlantic sturgeon and environmental predictors (Figure 29). Ocean bottom temperature between ~10-25 °C are predictive of Atlantic sturgeon occurrence, with bottom temperatures less than 10 °C associated with Atlantic sturgeon absence (Figure 29). In the previous section we showed a significant relationship between sturgeon and coarse sand, and an avoidance of very coarse sand and medium sand, however in the effects plot of the continuous variable Wentworth sediment grain size, there we see evidence for avoidance of large grain sizes (small Φ, Appendix A1.1.), and preference for smaller grain sizes (higher Φ, Appendix A1.1., Figure 29). We also see preference for stations that were characterized by higher bottom slope, likely related to the strong preference for receivers near the large sand ripple and trough in the northwest corner of the array (Figure 2A, 29) The partial effect of a443 is relatively weak, contributing to slight avoidance at higher a443 (green) absorption values (Figure 29). This may be related to the seasonality of Atlantic sturgeon, which occur less frequently during the summer months, when “green” water, or highly productive surface water would be present in this region. Finally, there is a complex relationship between Atlantic sturgeon, SST and bottom depth, with preference for cooler water at all depths, and avoidance of deep water when the SST is warm (Figure 29).

Table 3. Generalized additive model performance statistics for predicting Atlantic sturgeon occurrence in the DE WEA including bottom type characteristics.

Environmental predictor variables are abbreviated for brevity. Bottemp = bottom temperature, wentworth = modeled Wentworth sediment type, a443 = absorption at 443 nm, sst = sea surface temperature. AIC = Akaike’s information criterion, Exp Dev = explained deviance, PCC = percent correctly classified, Sens = sensitivity, Spec = specificity, AUC = area under the curve.



	Model Run		CV				
Model Formula	**AIC**	**Exp Dev**	**R^2**	**PCC**	**Sens**	**Spec**	**AUC**
s(bottemp) + s(slope) + s(wentworth) + s(a443) + te(sst x depth)	**2150**	**0.21**	**0.23**	**0.75**	**0.79**	**0.75**	**0.84**
s(bottemp) + s(sst) + s(wentworth) + s(a443) + te(slope x depth)	2161	0.21	0.22	0.75	0.78	0.75	0.84
s(bottemp) + s(sst) + s(depth) + s(a443) + te(slope x wentworth)	2166	0.20	0.22	0.76	0.77	0.75	0.83
s(bottemp) + s(sst) + s(slope) + s(a443) + te(wentworth x depth)	2167	0.21	0.22	0.75	0.77	0.75	0.83
s(bottemp) + s(slope) + s(depth) + s(a443) + te(sst x wentworth)	2167	0.20	0.22	0.76	0.77	0.76	0.83
s(bottemp) + s(sst) + s(depth) + s(wentworth)	2170	0.20	0.22	0.76	0.77	0.75	0.83
s(bottemp) + s(sst) + s(depth) + s(wentworth) + s(slope) + s(a443)	2174	0.20	0.22	0.76	0.77	0.75	0.83
s(sst) + s(depth) + s(slope) + s(a443) + te(bottemp x wentworth)	2177	0.20	0.22	0.75	0.78	0.75	0.83
s(bottemp) + s(sst) + s(depth) + s(wentworth) + s(slope)	2178	0.20	0.22	0.76	0.76	0.75	0.83
s(depth) + s(wentworth) + s(slope) + s(a443) + te(bottemp x sst)	2181	0.20	0.21	0.75	0.76	0.75	0.83
s(sst) + s(wentworth) + s(slope) + s(a443) + te(bottemp x depth)	2183	0.20	0.22	0.75	0.80	0.75	0.83
s(bottemp) + s(sst) + s(depth)	2208	0.18	0.20	0.75	0.78	0.74	0.82
s(bottemp) + s(sst)	2327	0.13	0.15	0.72	0.74	0.71	0.77
s(bottemp)	2534	0.05	0.06	0.57	0.72	0.56	0.67

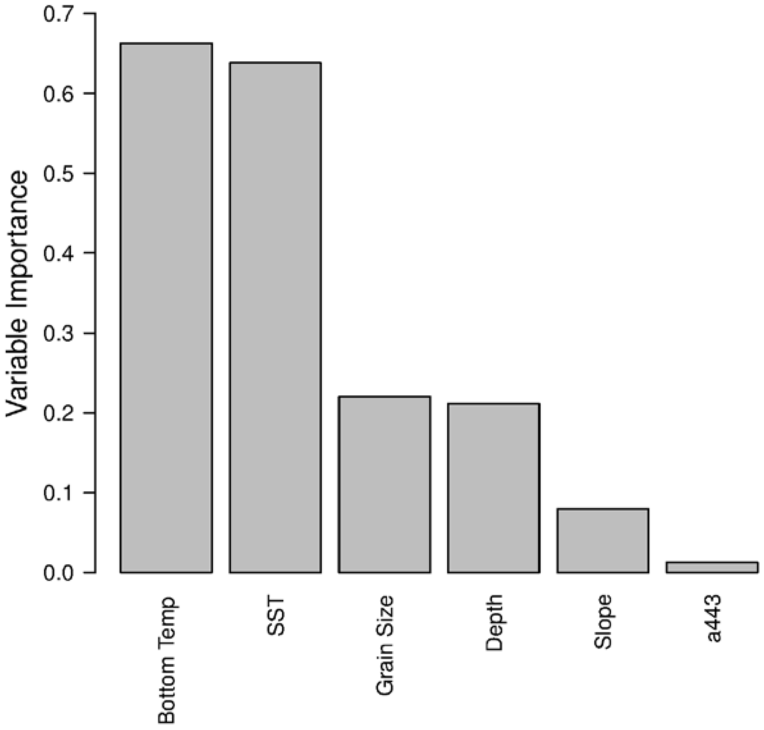


Figure 28. Variable importance of predictors in best performing GAM model for predicting Atlantic sturgeon occurrence in DE WEA.

SST = sea surface temperature, Slope = bottom topography slope, a443= absoption at 443 nm.

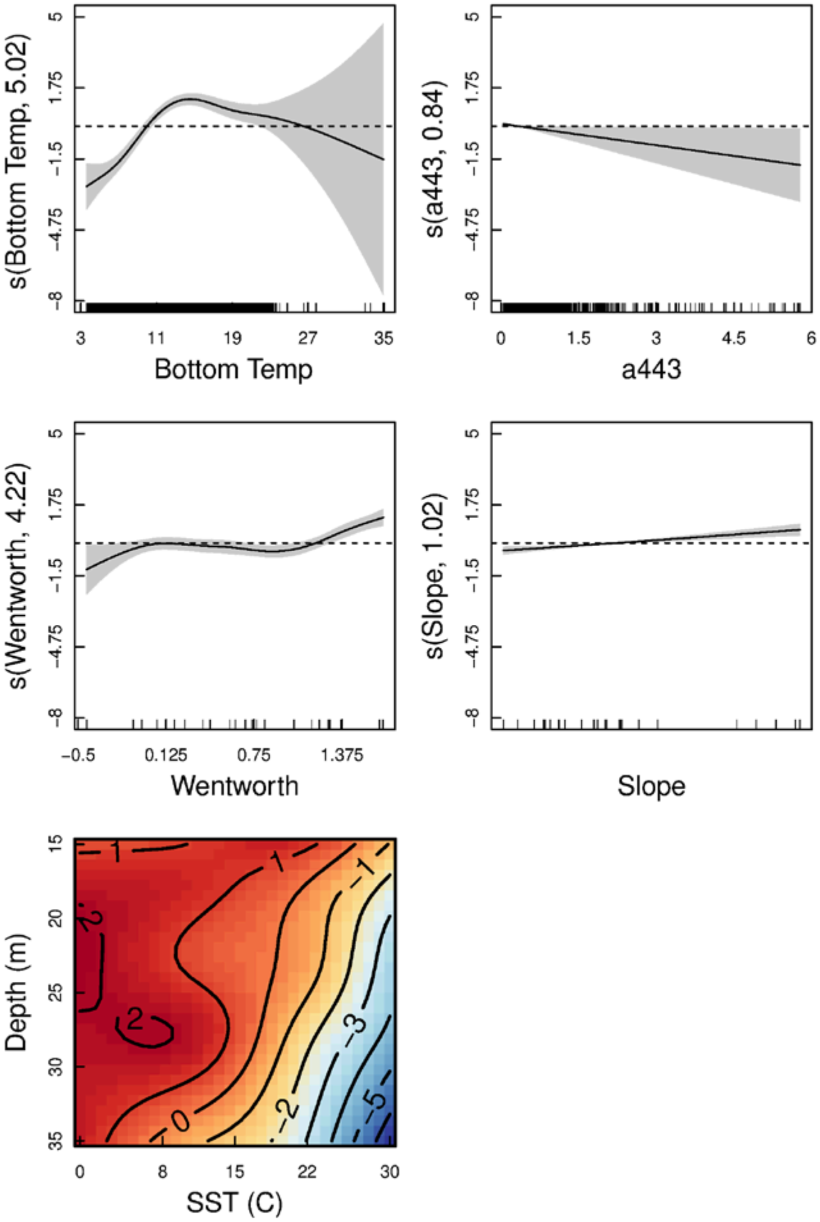


Figure 29. Predictor variable response functions for generalized additive models predicting the binomial response of Atlantic sturgeon in the DE WEA.

Black lines: smoothed curve of partial additive variable effect on probability of presence; dashed lines: 95% confidence interval. Partial variable responses > 0 are predictive of sturgeon occurrences, while partial variable responses < 0 are predictive of absences. Short vertical lines (rug) on the x-axis of single variable plots represent the distribution of variable observations upon which the model's response was built. Wentworth = modeled Wentworth sediment grain size (higher Φ = smaller grain size), a443= absoption at 443 nm (green), SST = sea surface temperature, Slope = bottom topography slope.

8.3 Seasonal Predicted Distribution in DE WEA

Using monthly climatologies of environmental predictor variables, we created prediction maps to assess the spatial output of the best performing GAM model for predicting Atlantic sturgeon occurrence in the DE WEA. Model performance statistics are comparable to published models for Atlantic sturgeon in the general Mid-Atlantic region (Breece et al. 2018; Ingram et al. 2019), differing slightly in the partial effects plots and model design. Predicted occurrence patterns for Atlantic sturgeon seem to match up well in both space and time with observed Atlantic sturgeon occurrences (Figures 16, 30). Predicted presence of Atlantic sturgeon is low January through April, with low occurrence predicted to occur in the northeast corner of the DE WEA, as well as in the seafloor channel in the northwest corner of the WEA (Figure 30). Beginning in May, as the Atlantic sturgeon migrate into the area in higher abundance, the model predicts heavy use of the northern portion of the WEA, in particular the shallowest areas in the northwestern corner by Atlantic sturgeon (Figure 30). This pattern is predicted to persist through October, when Atlantic sturgeon distribution expands across the entire WEA for November through December (Figure 30). These predicted patterns based on environmental parameters correlate well with patterns discussed in earlier sections and give us confidence that this model is useful to understand the distribution of Atlantic sturgeon throughout the entire array, even though our receivers were only able to monitor the perimeter.

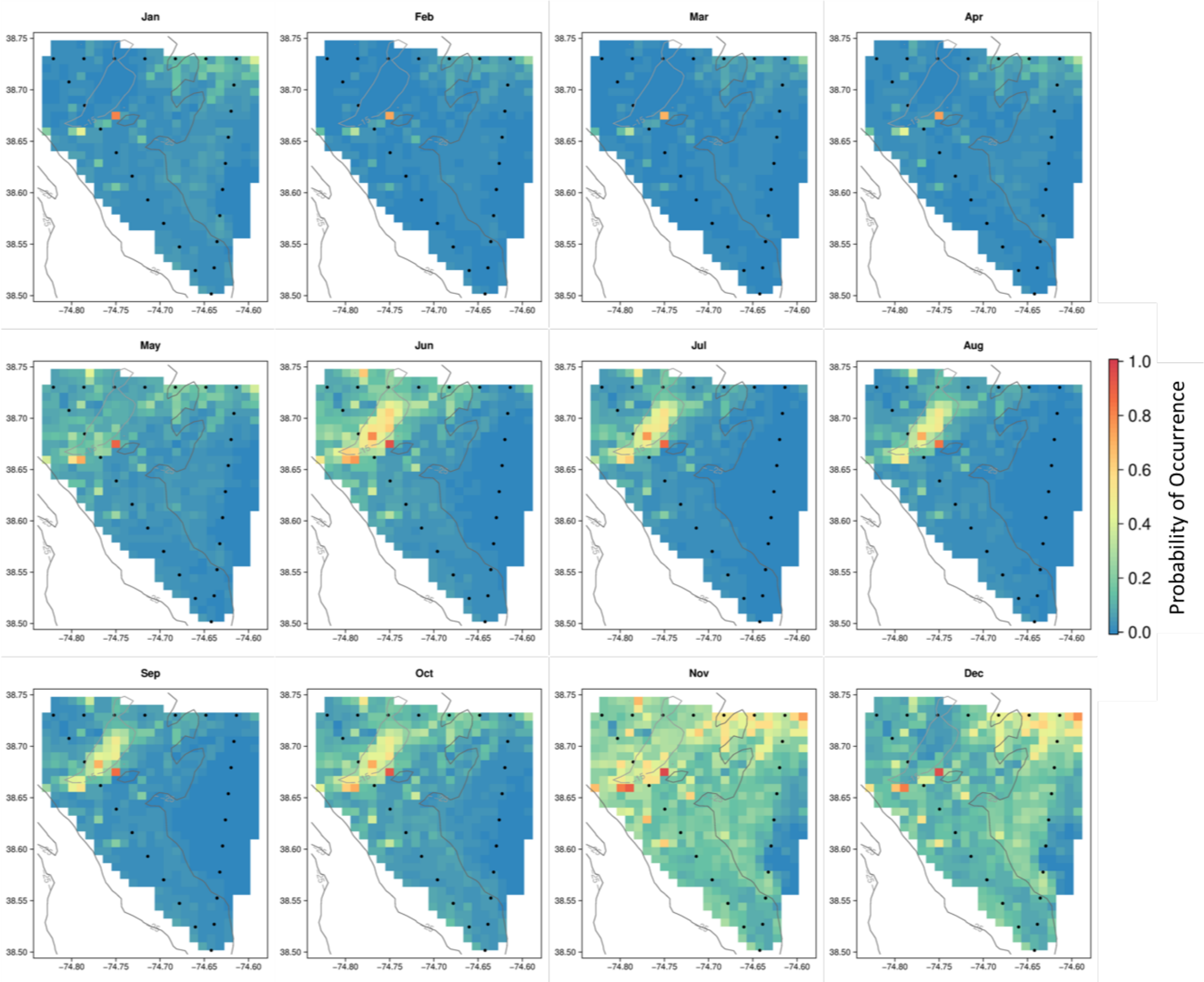


Figure 30. Predicted Atlantic sturgeon occurrence for best GAM model including bottom type characteristics.

Climatologies of environmental predictor variables and the best performing GAM model were used to create predicted occurrence maps for Atlantic sturgeon in the DE WEA. Cool colors represent areas of low probability of occurrence, and warm colors are areas of high probability of occurrence.

9 Discussion

The objectives of this study were to document the occurrence and behavior of telemetered species that occurred in the potential offshore energy lease site off coastal Delaware. This information is necessary for BOEM to meet its obligations under the National Environmental Policy Act, the Endangered Species Act, and the Magnuson-Stevens Fishery Conservation and Management Act. Baseline acoustic telemetry data on these species has documented their seasonal presence/absence, habitat use, and migratory behavior which will inform environmental impact assessments for offshore renewable energy. The species observed, and especially one of our focal species (Atlantic sturgeon), could be negatively impacted by offshore wind energy development (Breece et al. 2018) through noise disturbance and displacement from feeding grounds, masking of their communication calls, and disruption of their migration pathways. In addition, the DE WEA is situated between shipping lanes near the mouth of DE bay and includes important fishing grounds (Bureau Of Ocean Energy Management 2012). Therefore, this multi-use area is important for both the marine animals that occur within the study region and for humans as well.

9.1 Observed Species Occurrence

This project documented use of the DE WEA by 26 different marine species that were carrying VEMCO acoustic transmitters. These species included recreationally and commercially important fish species (Atlantic cod, black sea bass, cobia, smooth dogfish, spiny dogfish, striped bass, winter skates, etc.), apex predators (blacktip sharks, bull sharks, sandbar sharks, thresher sharks, tiger sharks, white sharks, etc.), marine mammals (gray seal, harbor seal), and endangered species or species of concern (Atlantic bluefin tuna, Atlantic sturgeon, dusky sharks, sand tiger sharks). This study confirms the presence of and therefore the likelihood of impacting many of the species highlighted by BOEM in early site characterization documents (Bureau Of Ocean Energy Management 2012, Section 4.1.2.7.1.1). Atlantic sturgeon and striped bass were the most commonly occurring species and are therefore most likely to be encountered. However, while Atlantic sturgeon occurrence was recorded year-round, striped bass presence was highly seasonal.

Patterns in occurrence were consistent across the two years of our study, with repeated seasonal patterns in distribution. Use of the DE WEA by marine fish and mammal species occurred year-round, although heaviest use occurred in the spring (Mar-May), and fall (Nov-Dec), driven by the high numbers of individual Atlantic sturgeon and striped bass migrating through the study area. High occurrences of Atlantic sturgeon during the late fall/early winter supports previous studies, which hypothesized that Atlantic sturgeon use coastal waters further offshore, including the DE WEA, during their southward fall migration (Figure 16, 26, Breece et al. 2018). Conversely, we observed very few northward migration events, as these events are likely occurring much closer to shore (Figure 16, 26, Breece et al. 2018).

Winter skate were observed in low abundance, but also occurred in the spring and late fall/early winter indicating that their presence in the study region may have been related to their migratory behaviors, and not long-term residency in the WEA. It is possible that their occurrence was low because the site is near the southern extent of their geographic range, or that this species prefers waters further inshore as their occurrence in the DE WEA was concentrated in the shallowest region (Michael G. Frisk and Miller 2009).

The timing of the occurrence of these species is likely related to water temperature preferences. Breece et al. 2018 found that SST and day of year largely explained the timing of Atlantic sturgeon presence in the nearshore coastal ocean. Similarly, our models included SST, further supporting that this is an important environmental variable for this species. Our models did not include day of year, but instead used modeled bottom temperature data which was highly correlated to day of year. While the ocean temperature likely defines the timing of Atlantic sturgeon and winter skate occurrence in the DE WEA, it does not vary on a small enough scale to explain the fine scale preferences for areas of intensive use that were observed during our study.

9.2 Atlantic Sturgeon Residency and Movement

Understanding the residency and movement behavior of Atlantic sturgeon in the study region allows managers to understand the likelihood of impacting this species. Residency events were observed for Atlantic sturgeon in the DE WEA most commonly in either late fall/early winter, when Atlantic sturgeon are preparing for migration, or are slowly migrating south for the winter (Figure 23, Breece et al. 2018), or during July, when the sturgeon may be seeking areas with cooler bottom temperatures offshore of Delaware Bay (Figure 12, Breece et al. 2018: Figure 3). The duration of residency events were comparable to previously documented residency events for Atlantic sturgeon, with most residency events lasting a few days, and the occasional event lasting multiple weeks (Breece et al. 2018; Ingram et al. 2019).

Transit rates within the DE WEA were comparable to those observed in the NY WEA and MD WEA (Ingram et al. 2019, E. Rothermal, *pers comm*). In addition, transit rates occurred most commonly in late fall/early winter, or in July (Figure 25). Because we observed both residency and non-residency events during these two times of the year (across both years of the study), we believe that Atlantic sturgeon occurrence and activity is highest in the DE WEA during July and Nov-Dec, and these are the months when there is the highest likelihood of encountering Atlantic sturgeon during construction or development of offshore wind energy projects.

9.3 Areas of Intensive Use

Species occurred throughout the entire perimeter of the DE WEA, however, we did note patterns in the areas of intensive use by key species. Our focal species, Atlantic sturgeon and winter skate, were commonly detected in both the northwestern and northeastern corners of the array, as well as along near the large sand ripple and seafloor channel along the western edge of the WEA. These areas may be frequented by these species due to the unique bottom characteristics (bathymetric features and sediment grain size) in this portion of the DE WEA. Bathymetry data reveals the presence of a channel that runs from the middle of the western edge of the array to the northeastern corner of the array. The northwestern corner is also the shallowest area of the DE WEA. However, it is unclear why these features may be attractive to Atlantic sturgeon. It is possible that these features are attractive because of small scale oceanographic features such as water flow and water mixing that may be enhanced by shallowing of the ocean floor, or Atlantic sturgeon may simply be attracted to the sediment grain size that is correlated with these features.

Previous surveys of the DE WEA have documented blue mussel reefs in the northwestern corner of the WEA, which may be an attractive prey item, or habitat for other types of prey (amphipods, worms, crustaceans, etc.) for both Atlantic sturgeon and winter skate (Johnson et al. 1997; Garrison and Link 2000; Guida et al. 2017). In addition, bottom surveys documented high occurrences of other benthic infauna including crustaceans and polychaetes, which occur throughout the DE WEA, but are also likely sought after prey items for our focal species (Johnson et al. 1997; Garrison and Link 2000; Guida et al. 2017). This region of the array is also dominated by crests and troughs of large mega-ripples, which may provide an attractive structure to many species, including our focal species (Guida et al. 2017). These sand ripples are also indicative of high rates of water flow, which we experienced first-hand when maintaining moorings in the middle of the western edge of the array and in the northeastern corner. High rates of water flow increase mixing and may overturn new feeding grounds as sand ripples are moved during tidal fluxes or strong storm events (Wright 1993; Glenn et al. 2008). Results from our habitat selection analyses and predictive species occurrence models indicate that bottom type and topography are related to the occurrence of Atlantic sturgeon in this region, and therefore likely explains the importance of these regions of intensive use by Atlantic sturgeon, and likely other species of interest as well.

10 Conclusions and Recommendations

Based on our initial two year study, we believe that it is likely that Atlantic sturgeon may be impacted by the offshore wind energy development projects in this region, however it is still unclear as to the level of impact the construction, maintenance and presence of the wind turbines might have on this species. Impacts on both Atlantic sturgeon and winter skate would be reduced if construction of wind turbines avoided the northern portion of the array. In addition, concentrating construction efforts to the summer months (June-September), would also reduce interactions with these species and most other species as this was the time of year when acoustic detections were fewest. Late fall and early winter (November-December) appears to be a very active time in the DE WEA, with multiple species migrating through the region.

To better understand the effects of the construction and presence of offshore wind turbines on species in the Mid-Atlantic, we suggest a continuation of this study to record the occurrence of telemetered species during the construction and operational phase. This would inform many of the other offshore wind turbine development projects in the Mid-Atlantic region, and benefit from having an established baseline dataset of species occurrence and distribution as provided by this project.

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Appendix A: Wentworth grain size chart

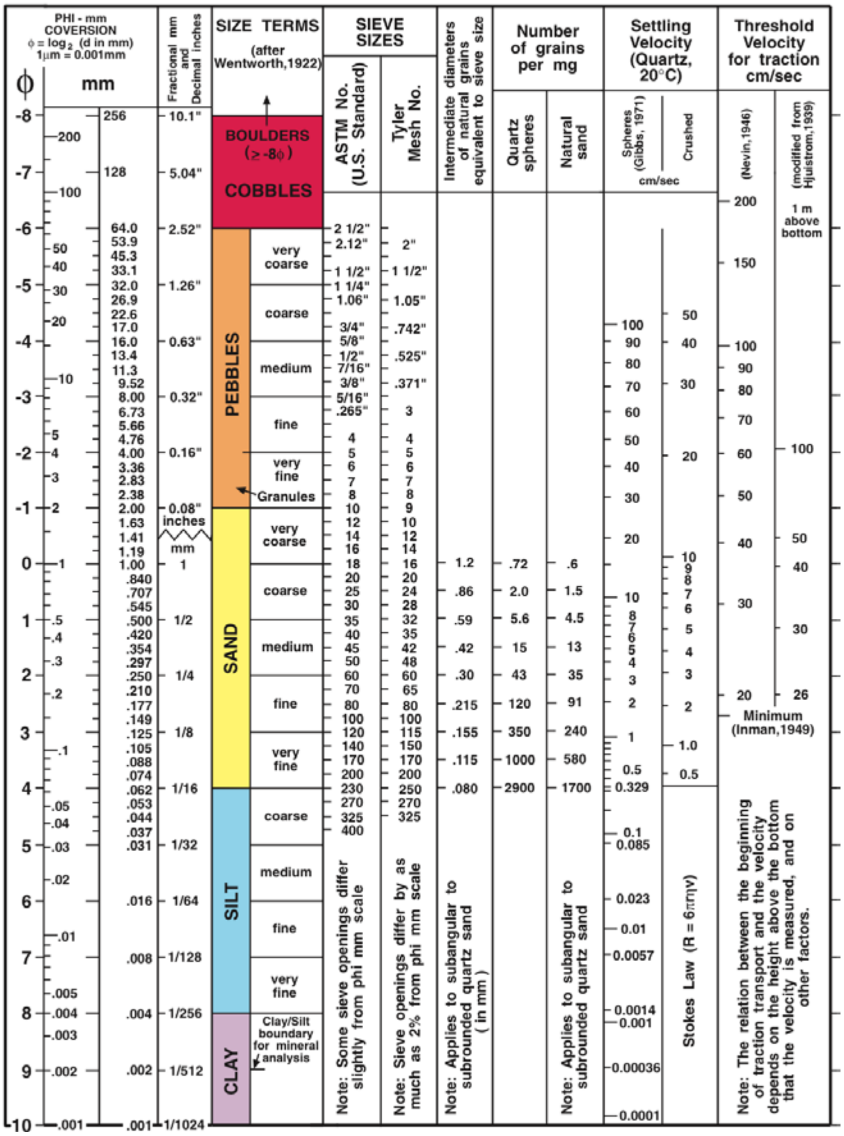

Figure A1.1. Wentworth grain size chart.
Chart used as guide when discussing Wentworth sediment grain size product used to classify habitat selectivity for Atlantic sturgeon and winter skate in the DE WEA. From: United States Geological Survey Open-File Report 2006-1195, “Surficial sediment character of the Louisiana offshore continental shelf region: A GIS Compilation” by Jeffress Williams, Matthew A. Arsenault, Brain J. Buczkowski, Jane A. Reid, James G. Flocks, Mark A. Kulp, Shea Penland, and Chris J. Jenkins.

Appendix B: All Species Observed Occurrences by Month

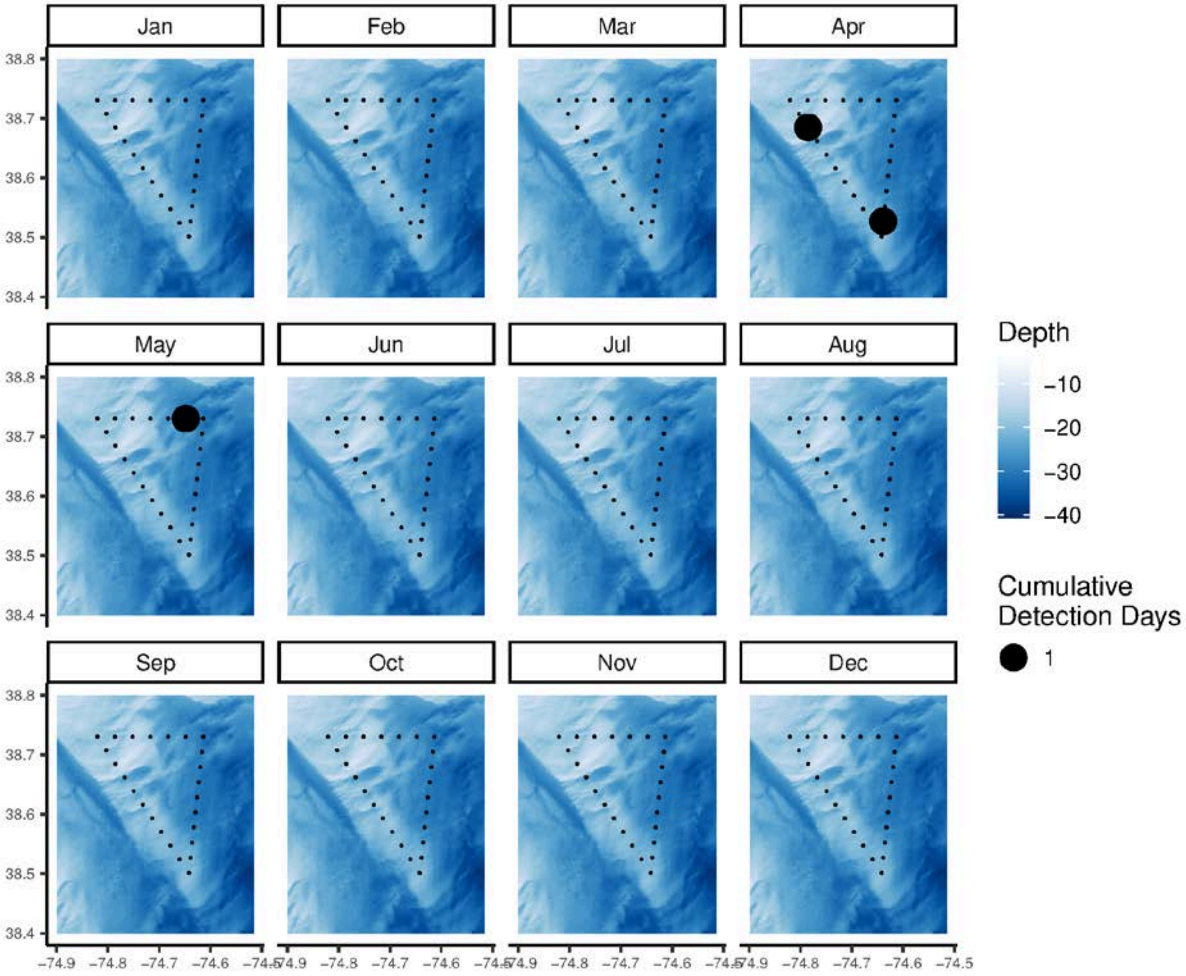

Figure B1.1. Spatial distribution of detections of American shad on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all American shad recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

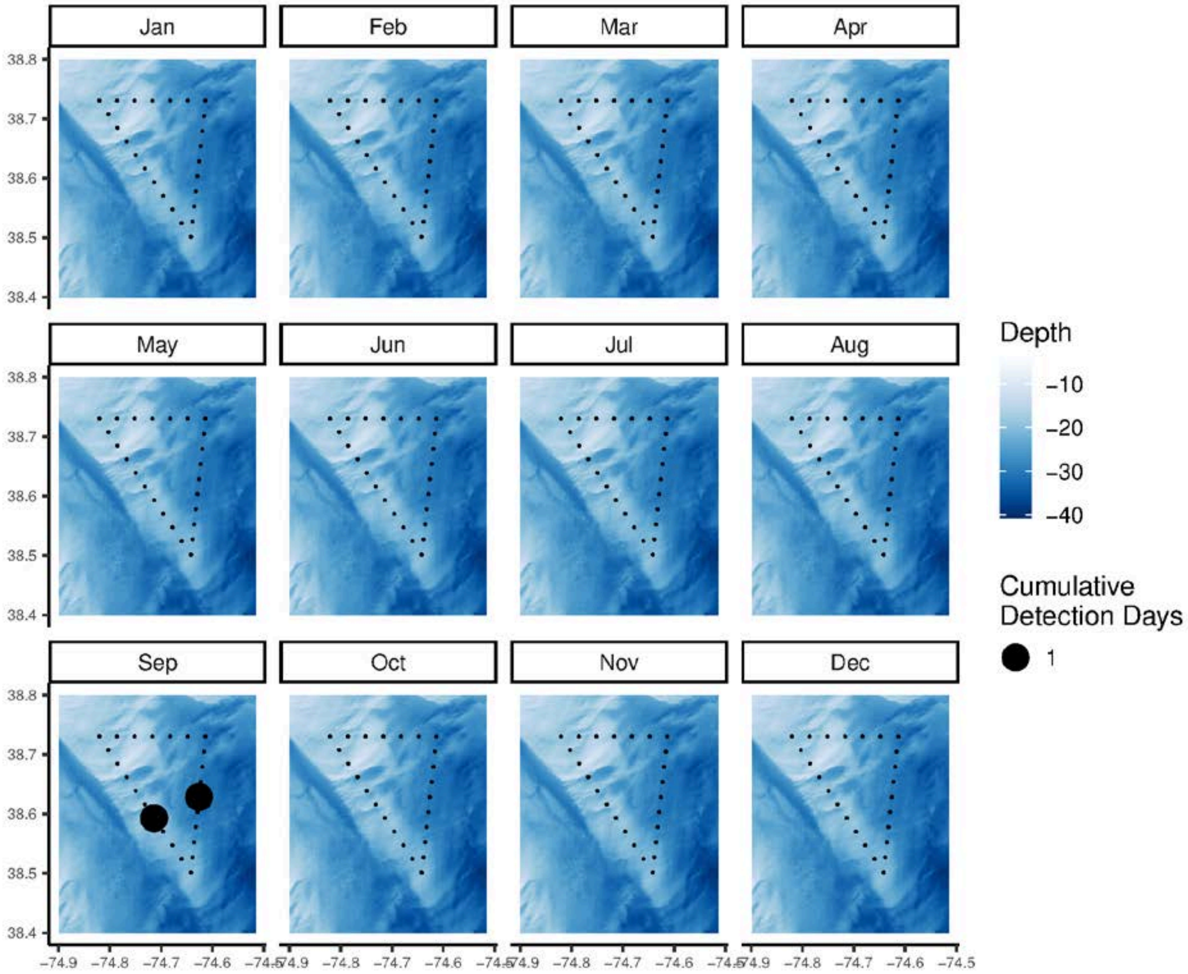

Figure B1.2. Spatial distribution of detections of Atlantic angel shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all Atlantic angle sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

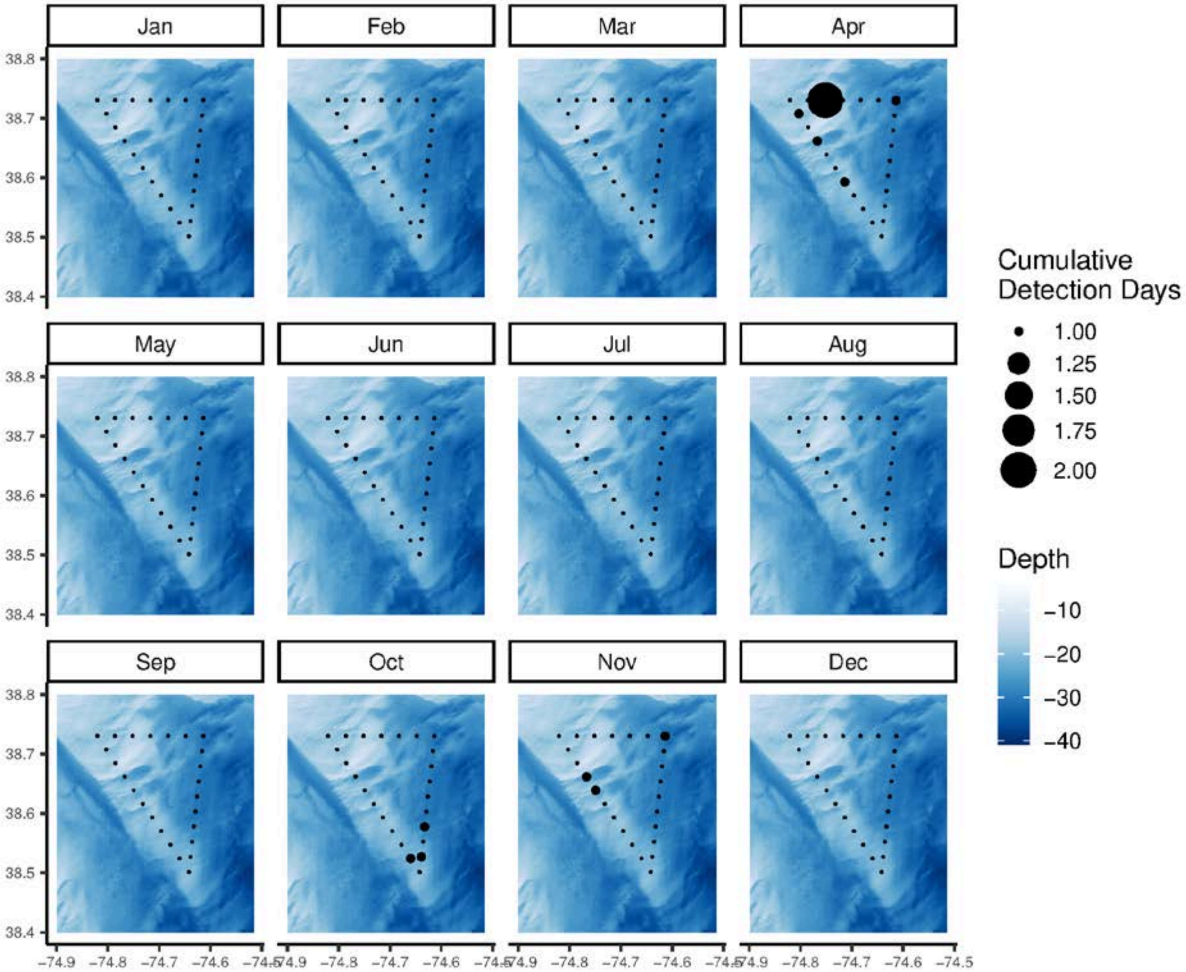

Figure B1.3. Spatial distribution of detections of Atlantic bluefin tuna on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all Atlantic bluefin tuna recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

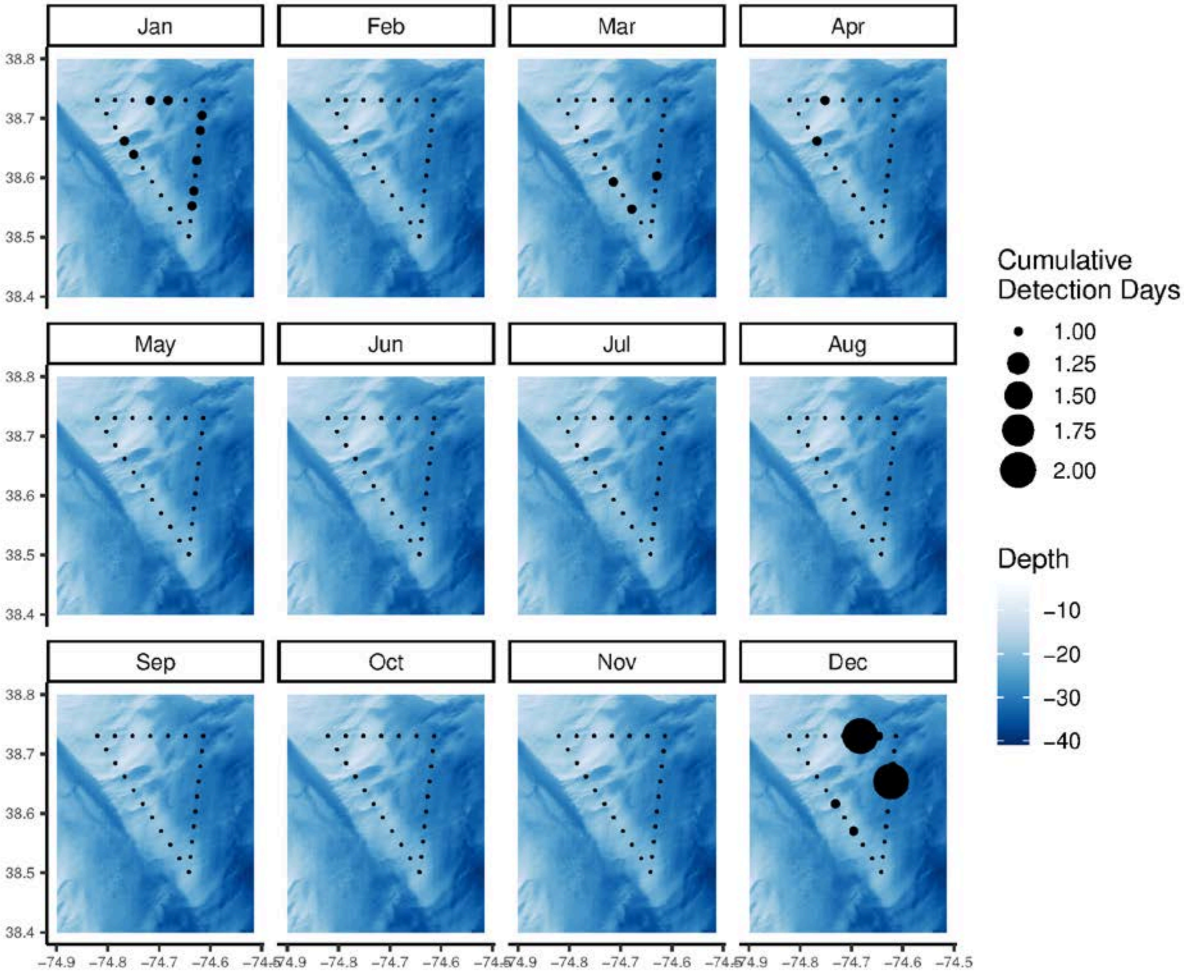

Figure B1.4. Spatial distribution of detections of Atlantic cod on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all Atlantic cod recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

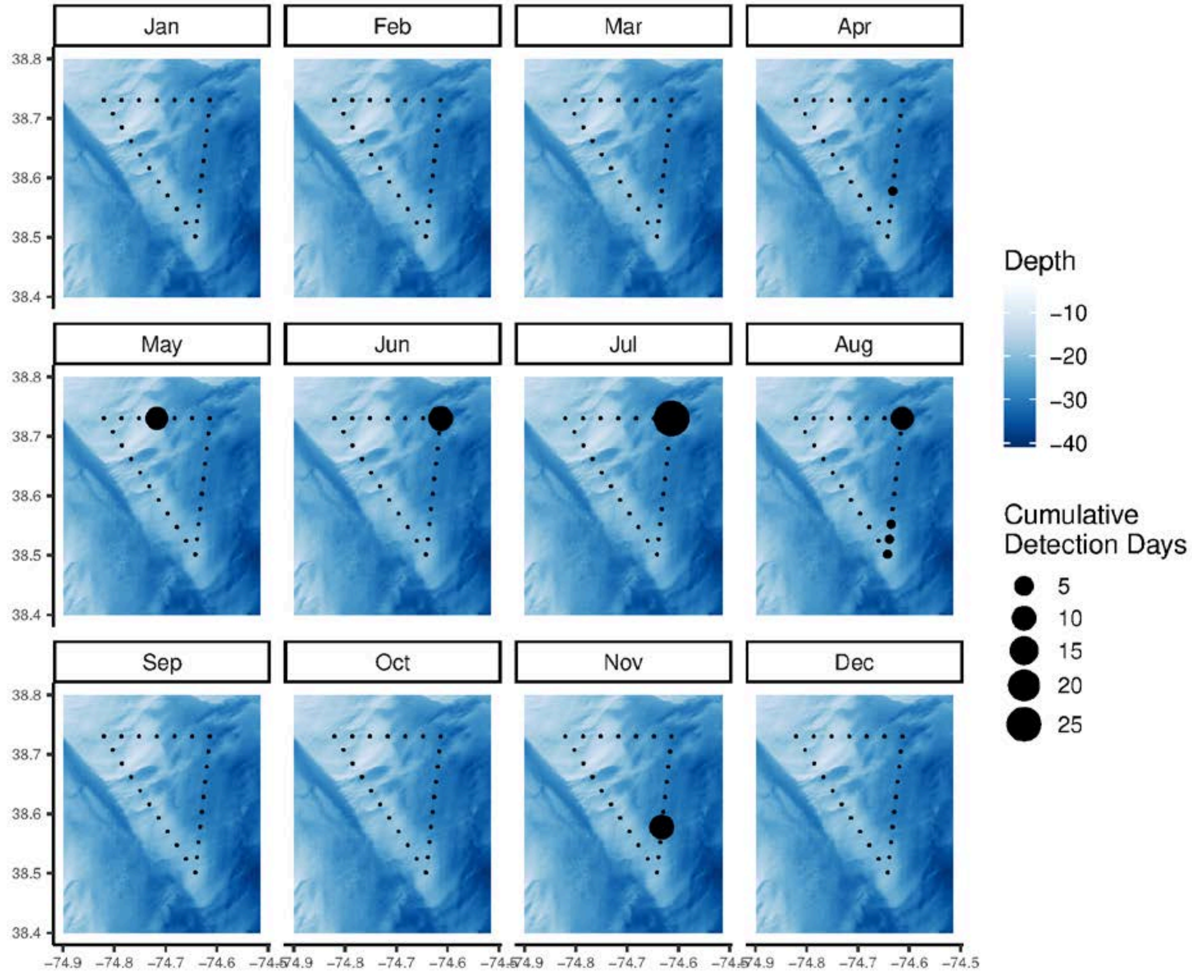

Figure B1.5. Spatial distribution of detections of black sea bass on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all black sea bass recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

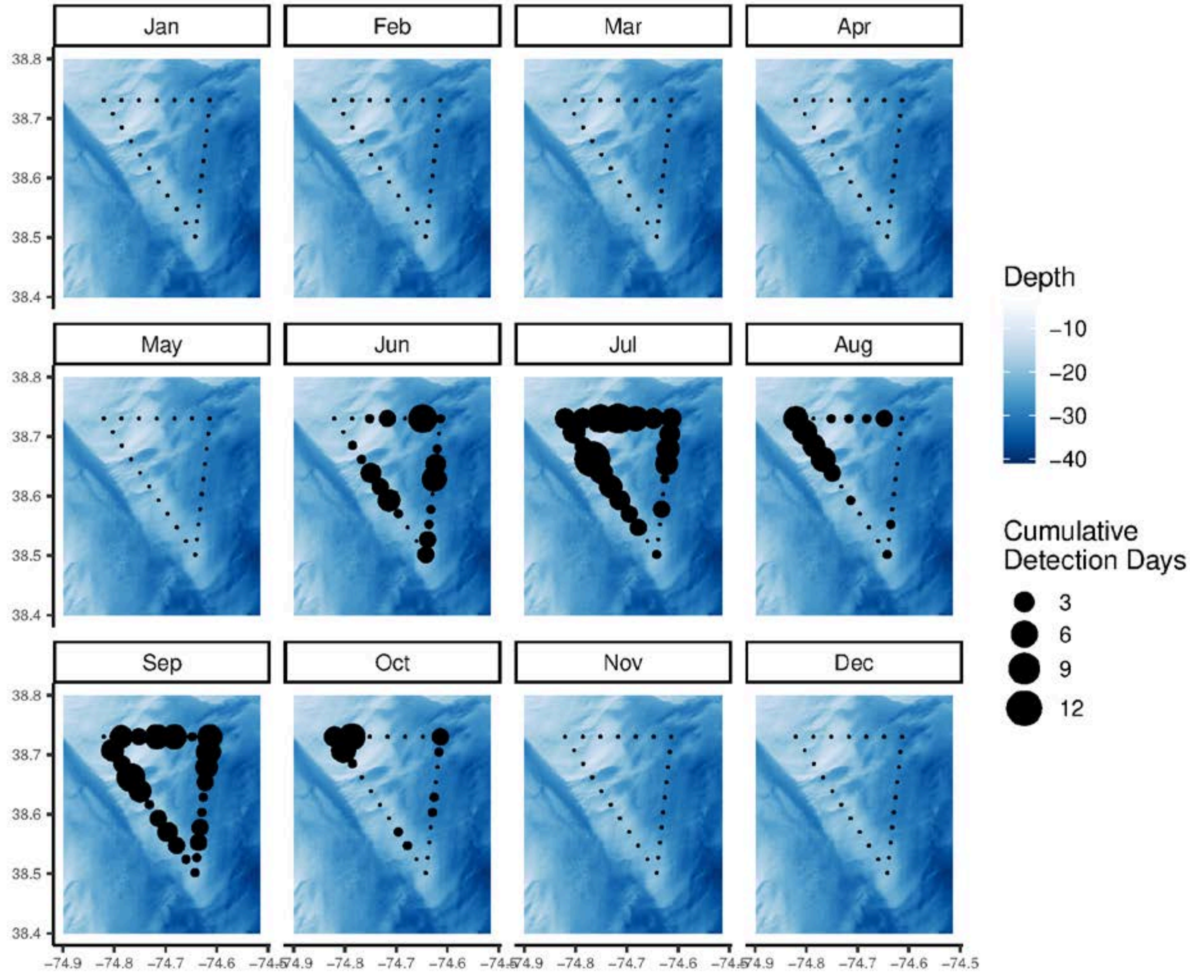

Figure B1.6. Spatial distribution of detections of blacktip shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all blacktip sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

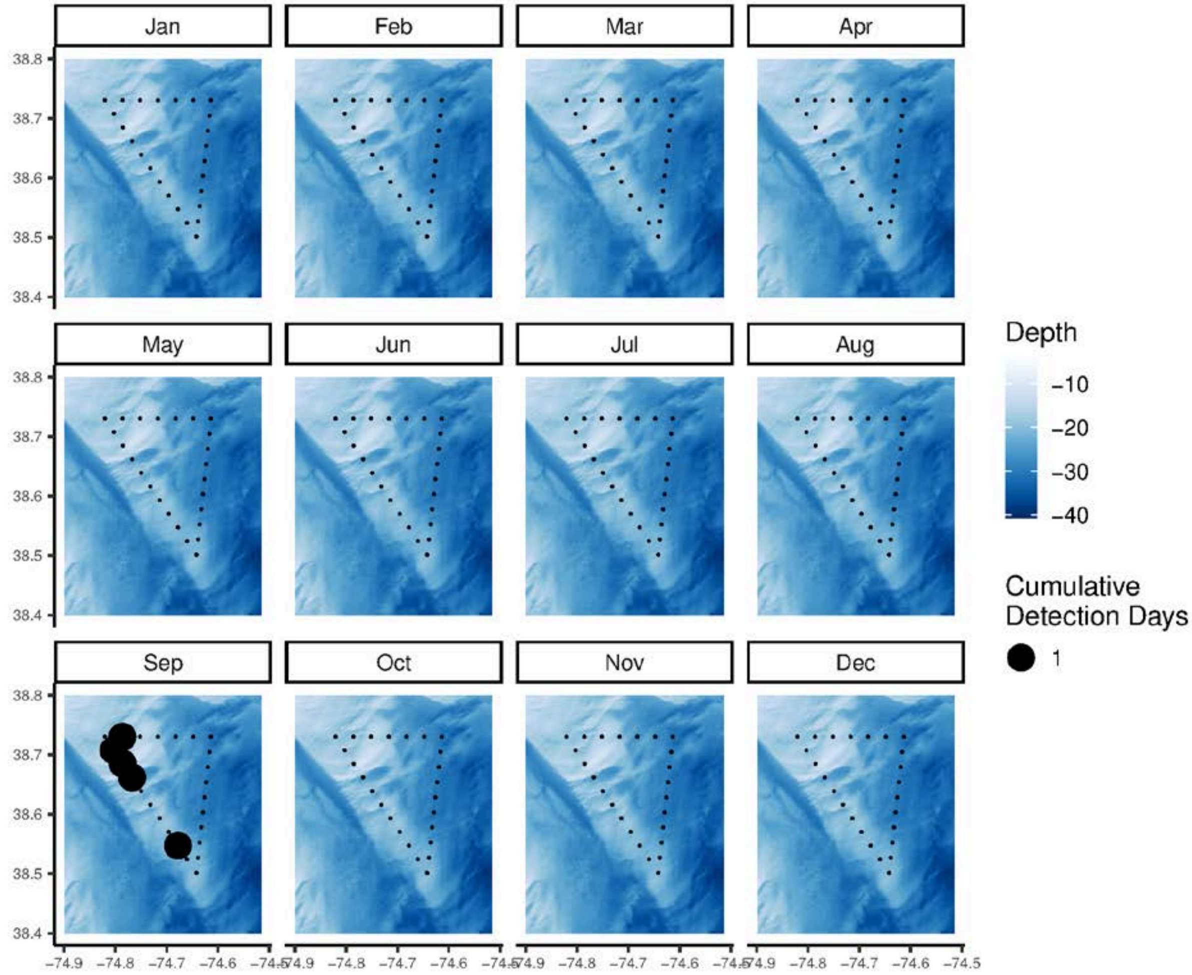

Figure B1.7. Spatial distribution of detections of bull shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all bull sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

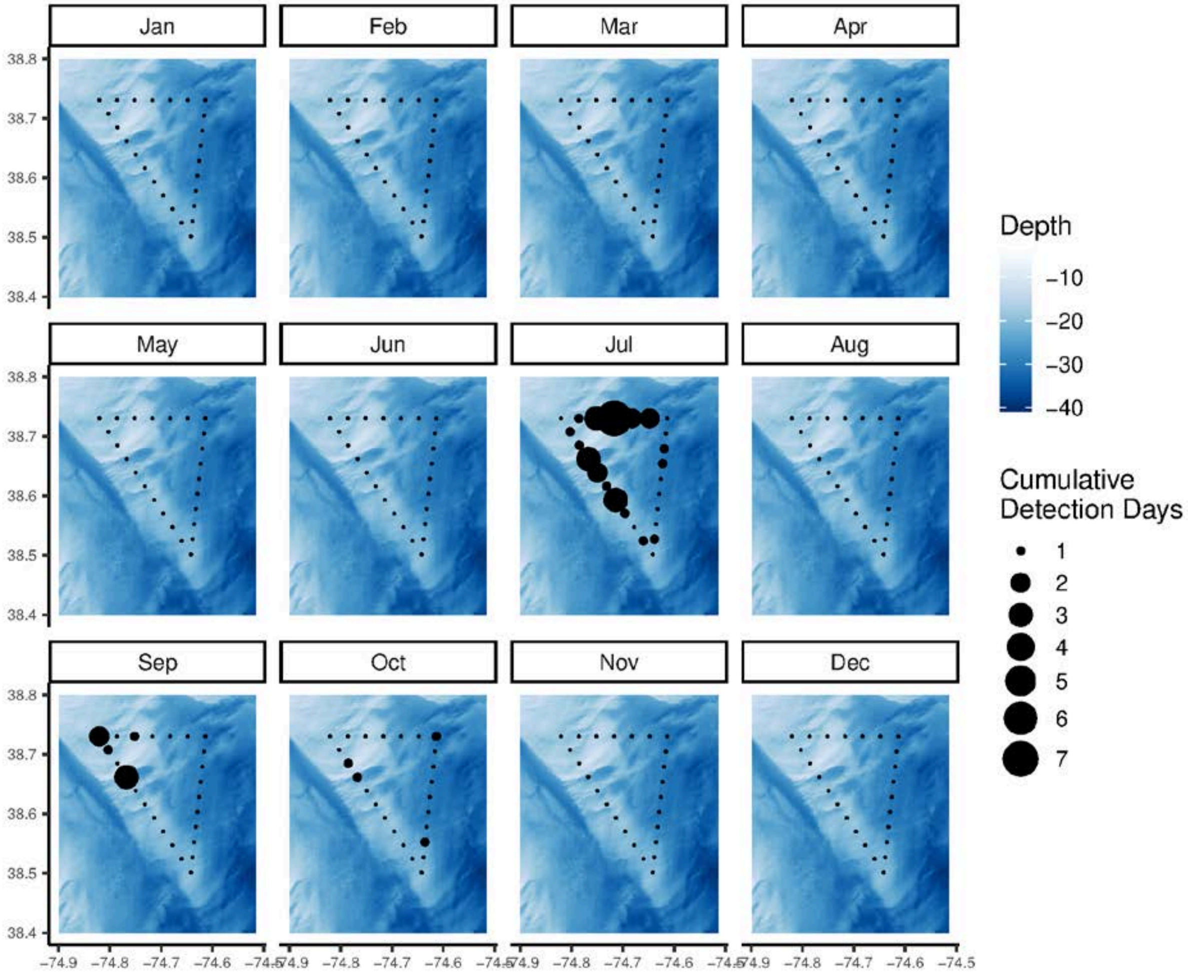

Figure B1.8. Spatial distribution of detections of cobia on receivers of the DE WEA by month. Black circles represent receiver locations and are sized by the cumulative number of detection days for all cobia recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

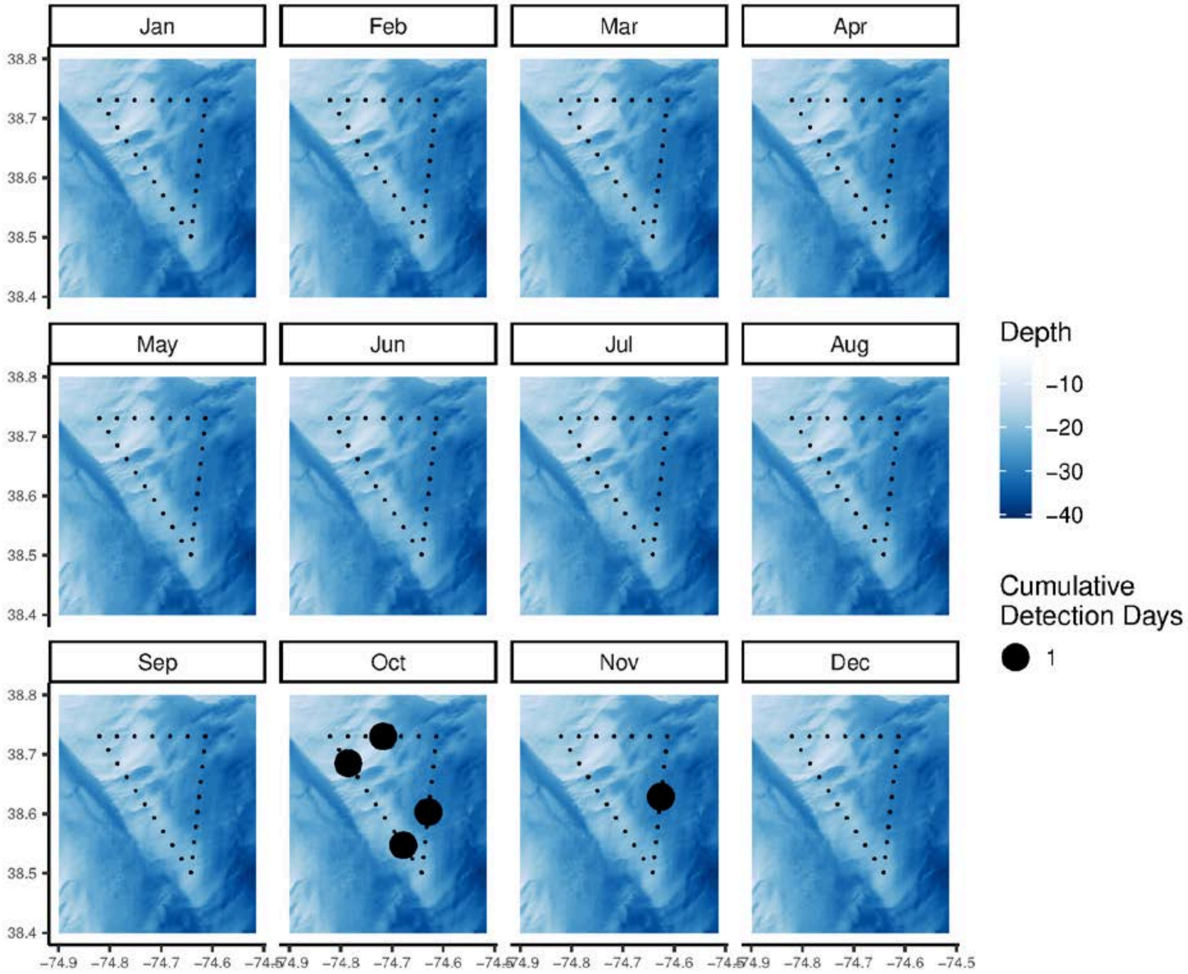

Figure B1.9. Spatial distribution of detections of cownose ray on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all cownose ray recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

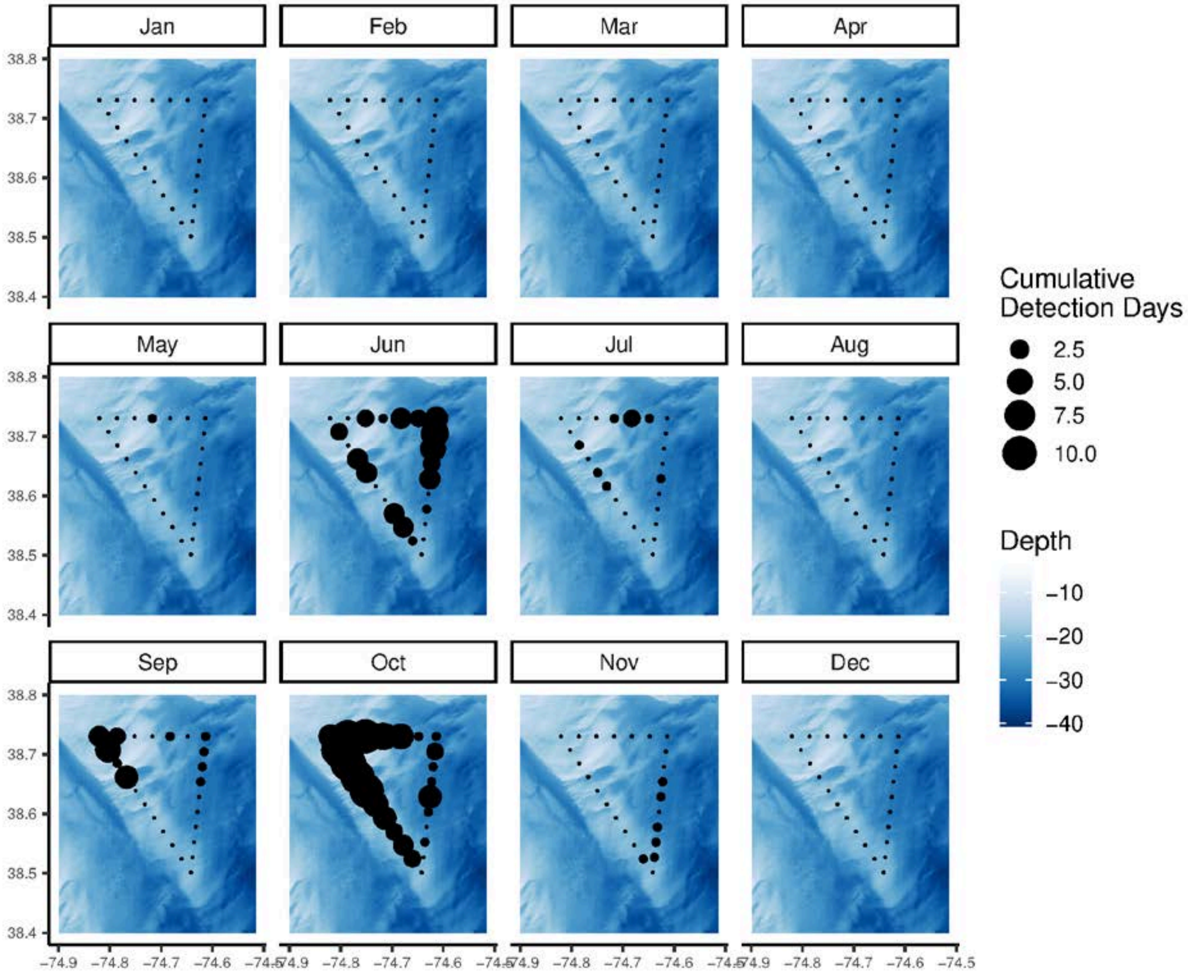

Figure B1.10. Spatial distribution of detections of dusky shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all dusky sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

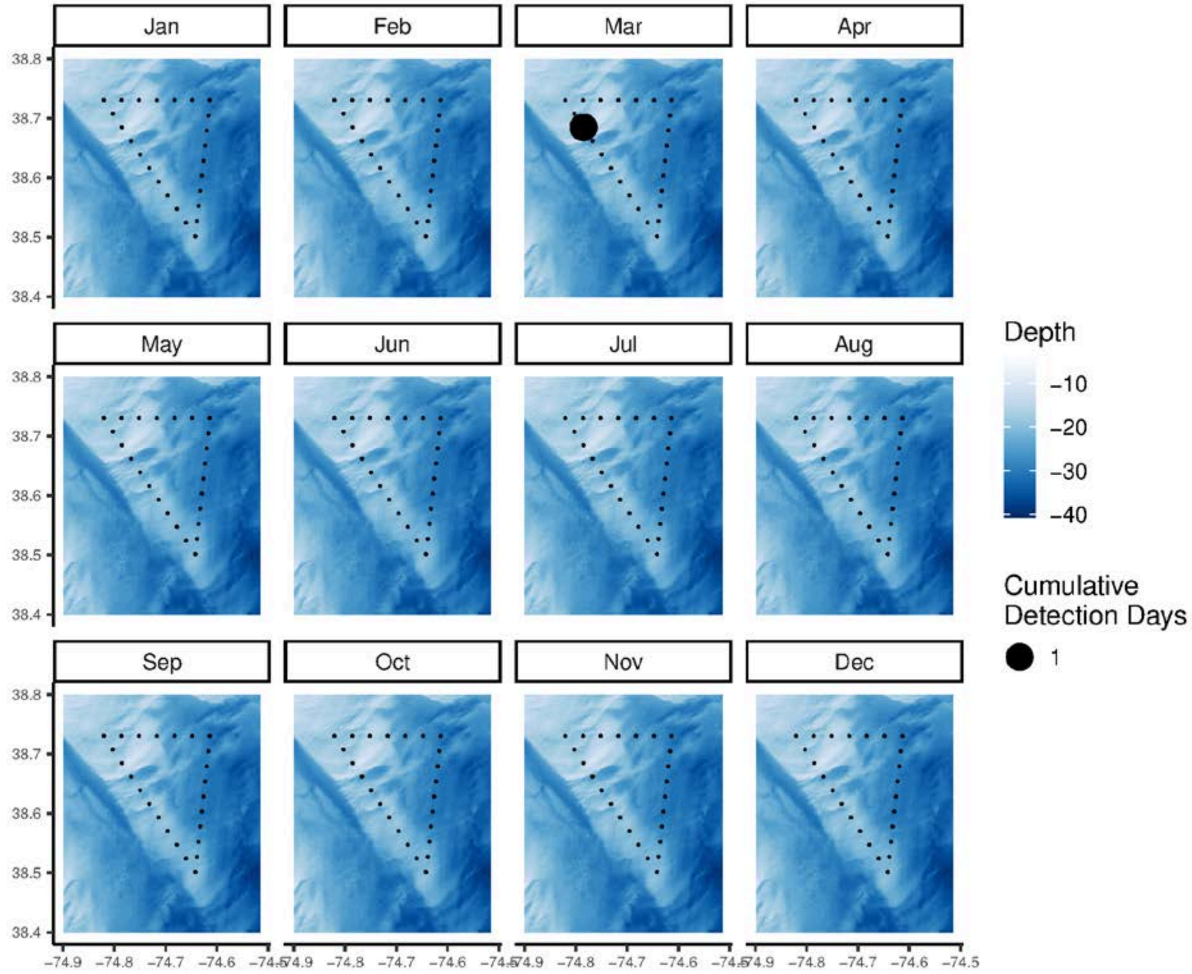

Figure B1.11. Spatial distribution of detections of gray seal on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all gray seals recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

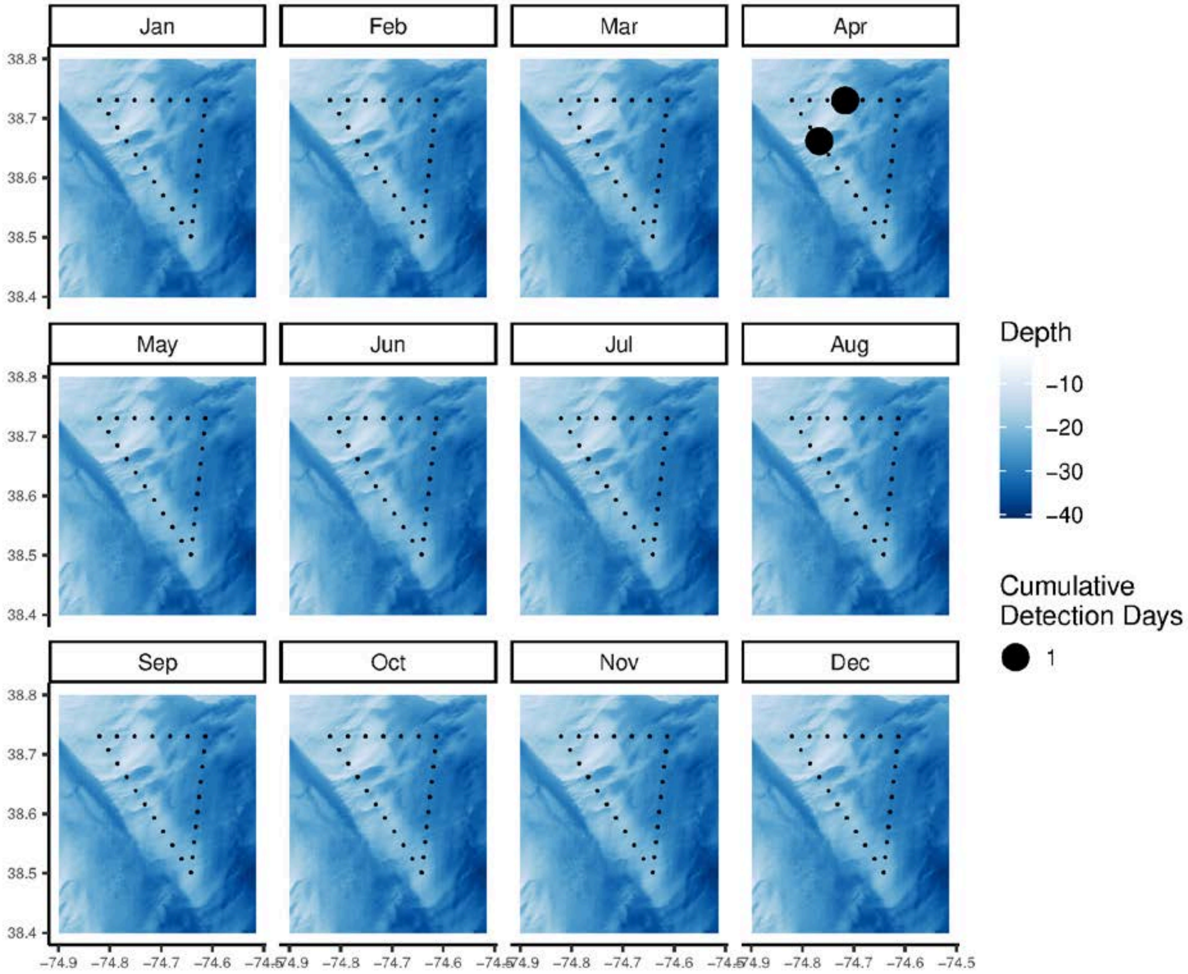

Figure B1.12. Spatial distribution of detections of harbor seal on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all harbor seals recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

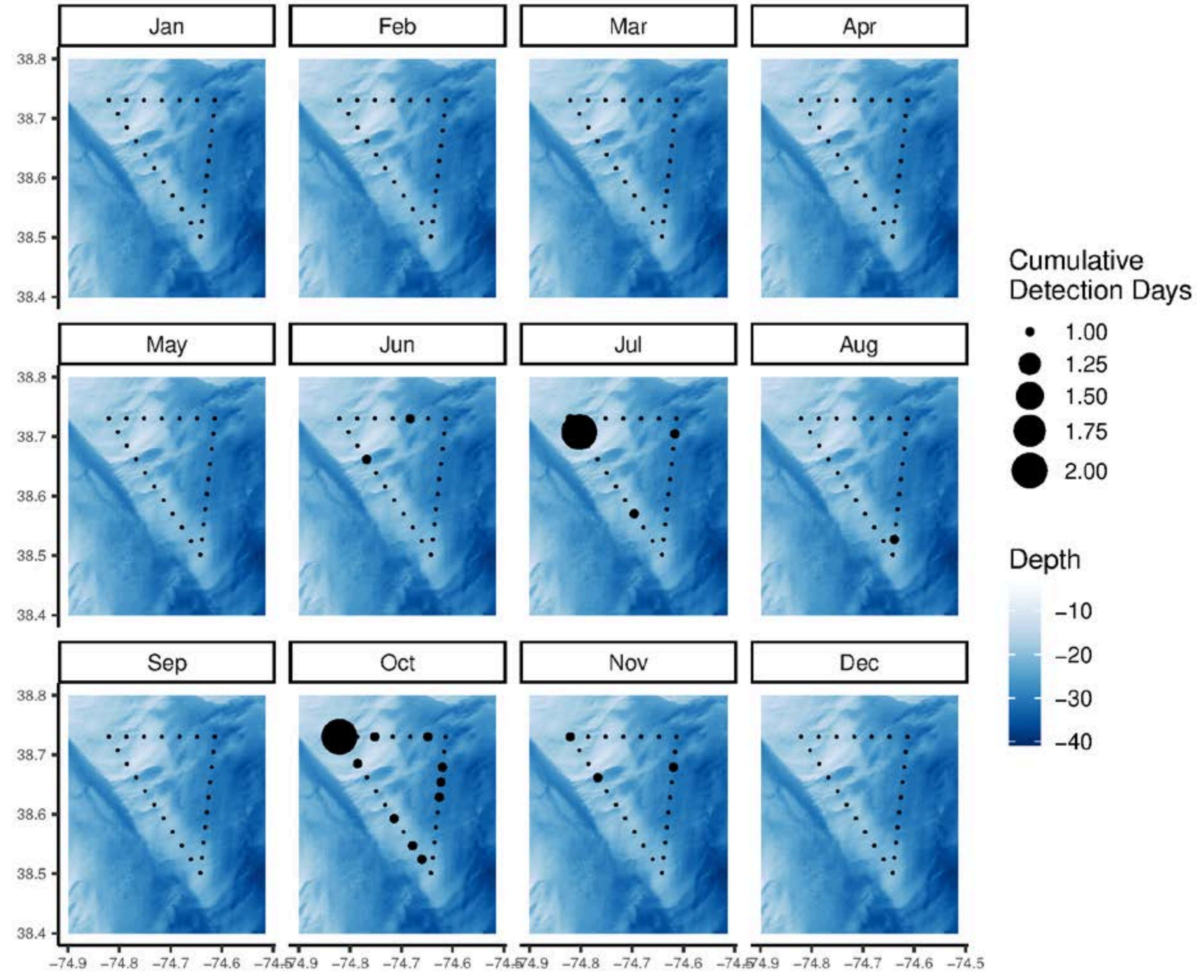

Figure B1.13. Spatial distribution of detections of sand tiger shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all sand tiger sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

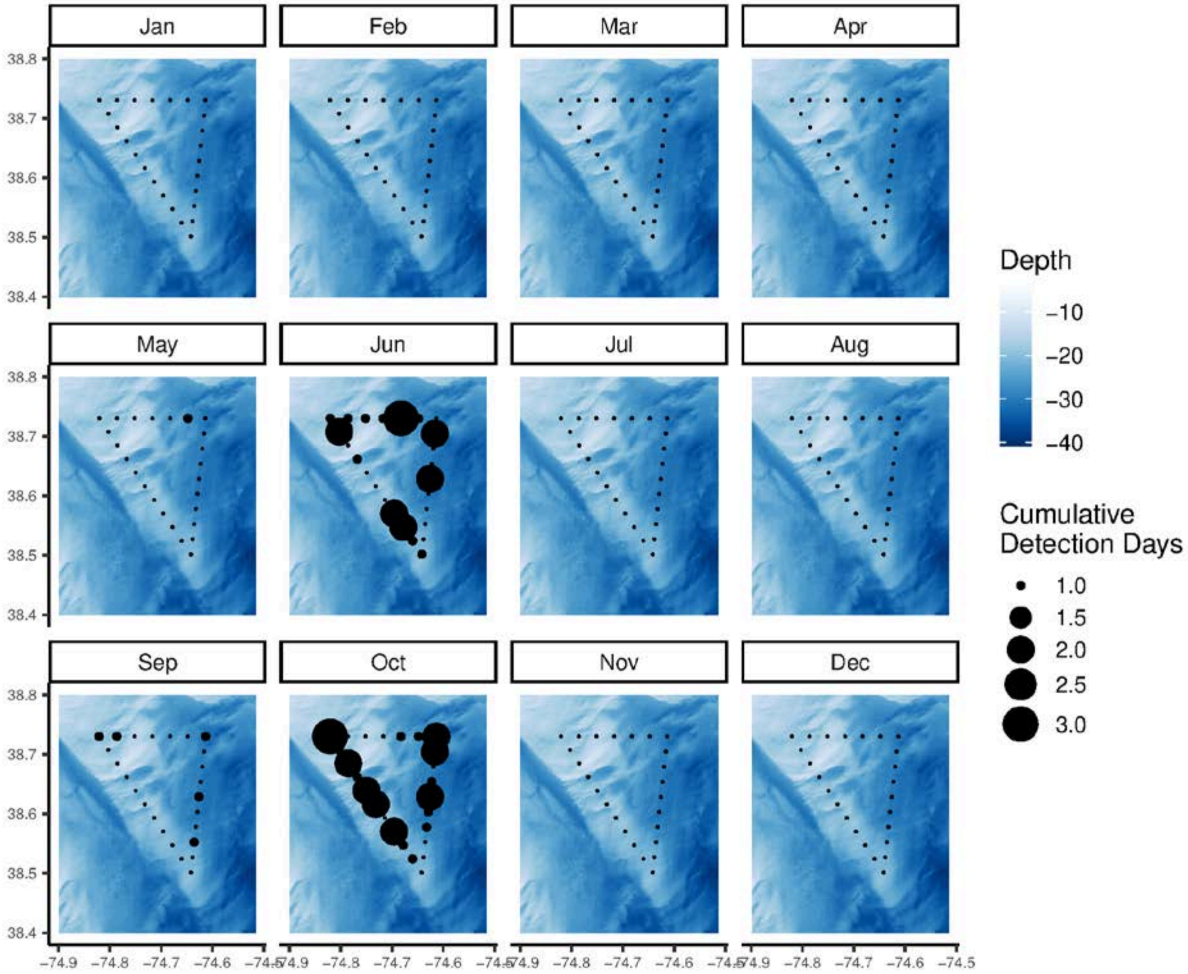

Figure B1.14. Spatial distribution of detections of sandbar shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all sandbar sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

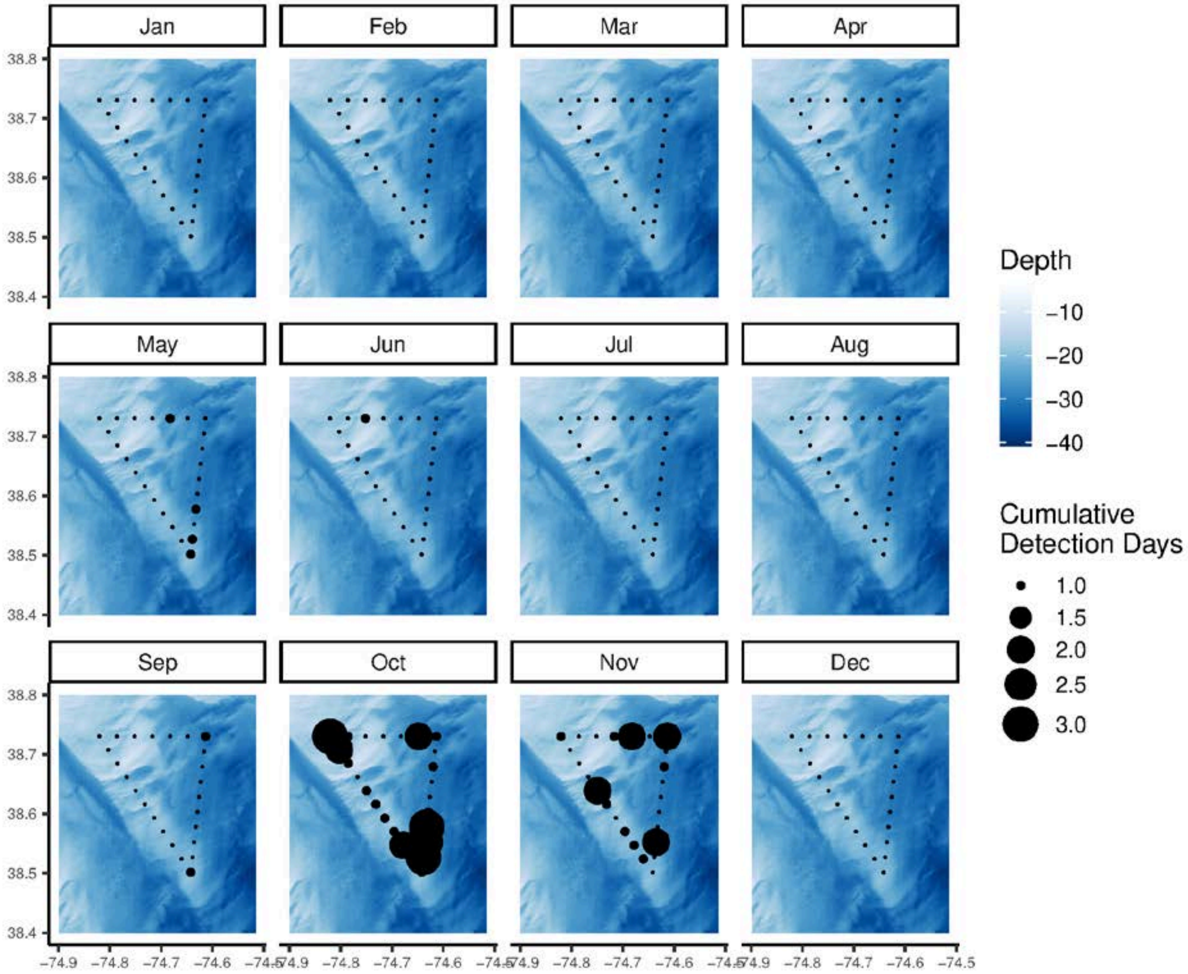

Figure B1.15. Spatial distribution of detections of smooth dogfish on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all smooth dogfish recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

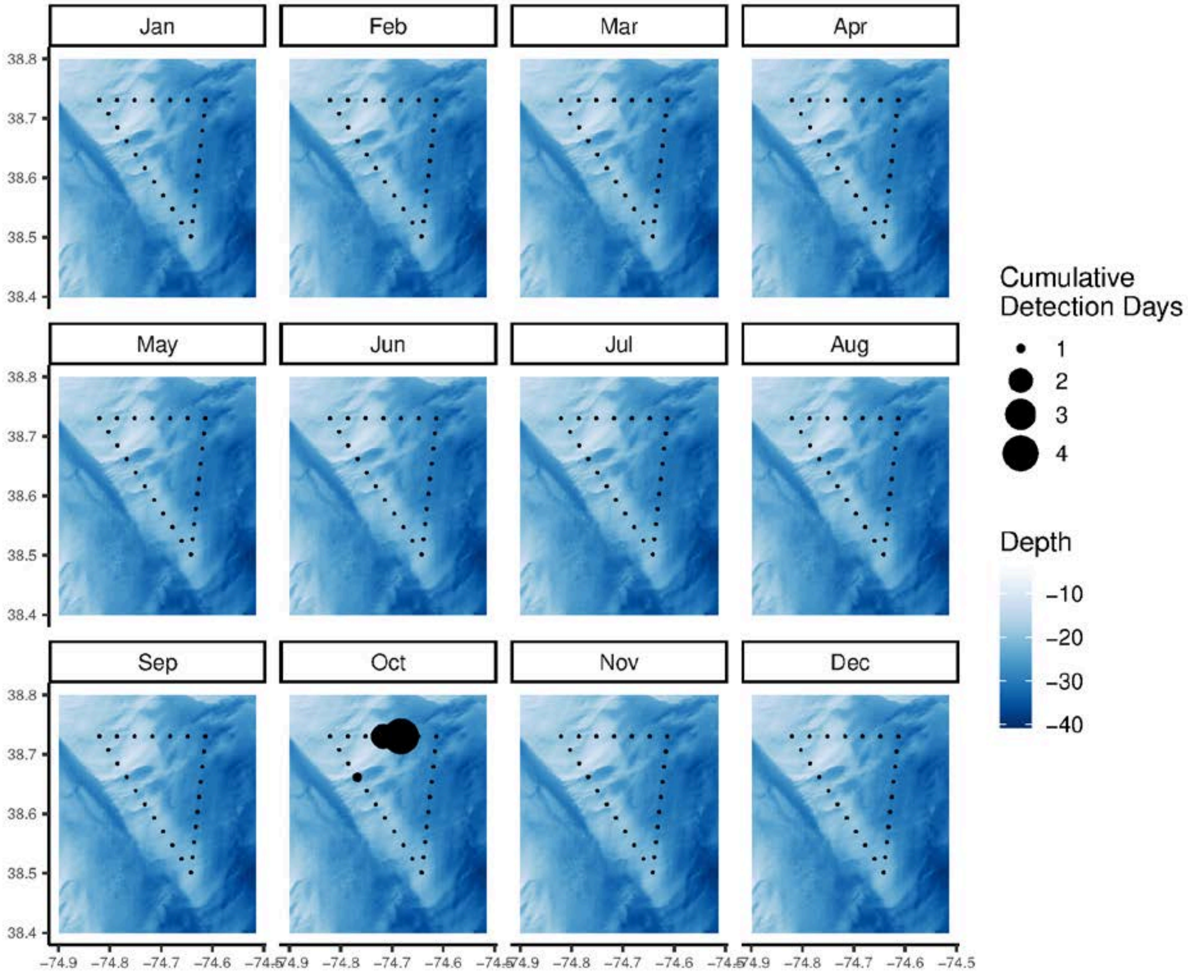

Figure B1.16. Spatial distribution of detections of southern stingray on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all southern stingray recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

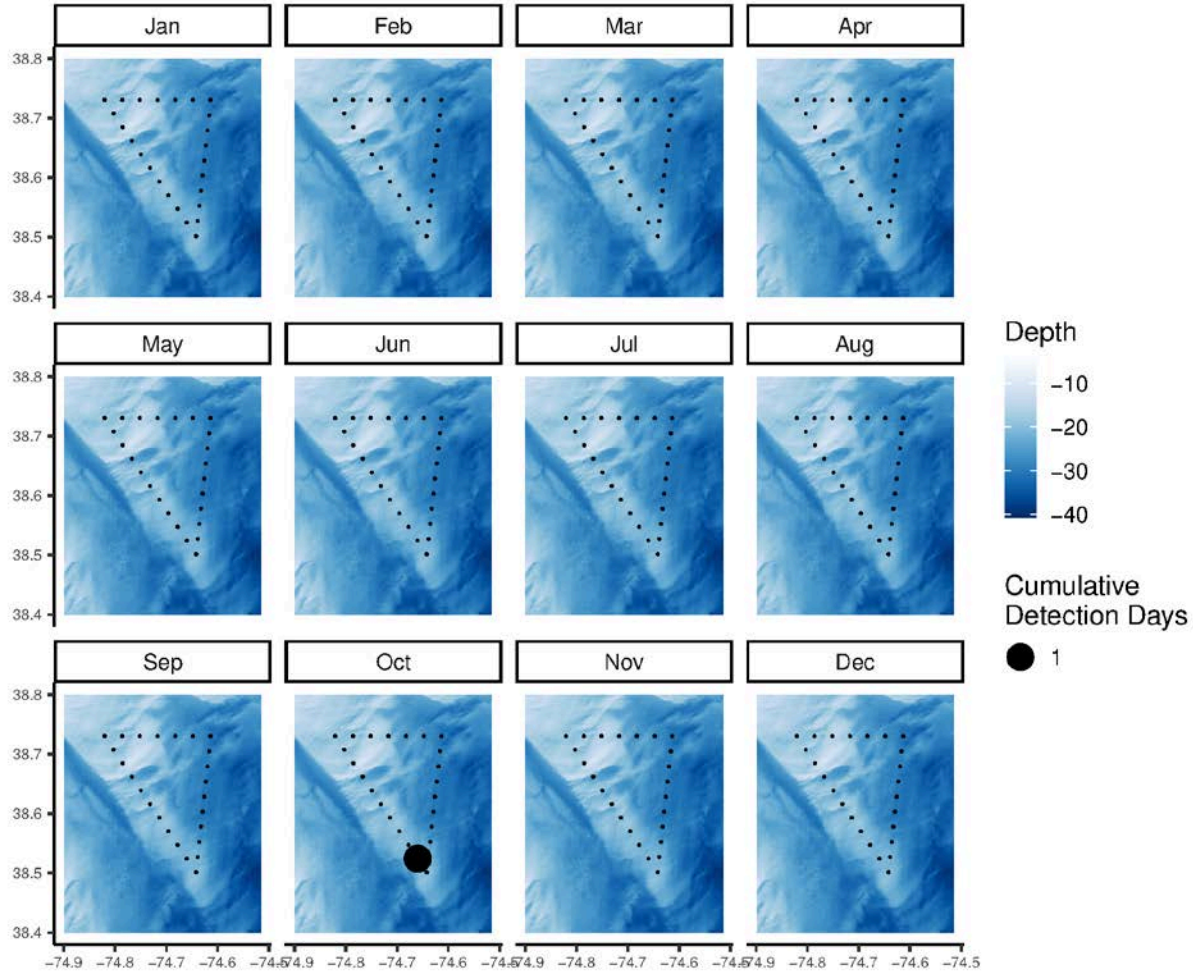

Figure B1.17. Spatial distribution of detections of spinner shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all spinner sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

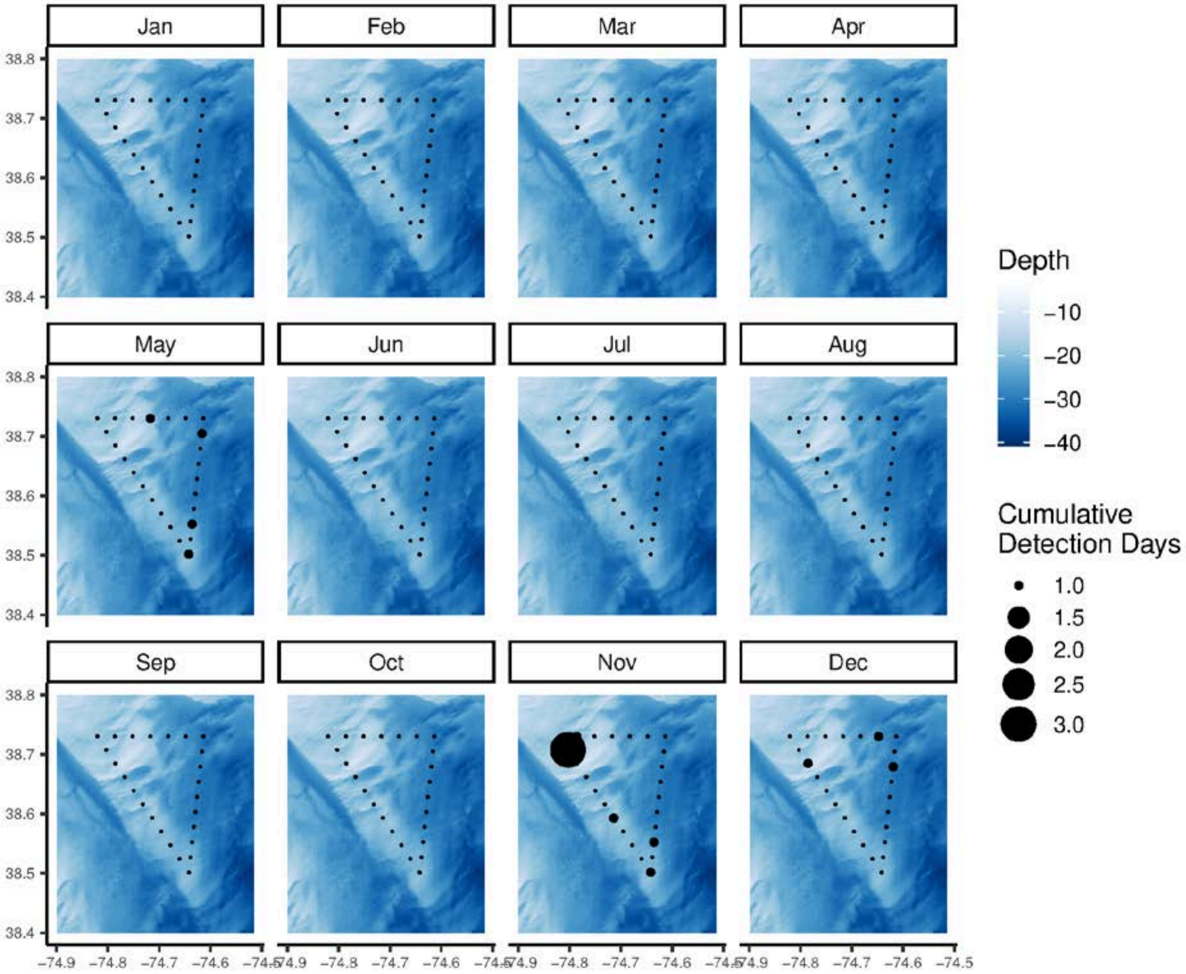

Figure B1.18. Spatial distribution of detections of spiny dogfish on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all spiny dogfish recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

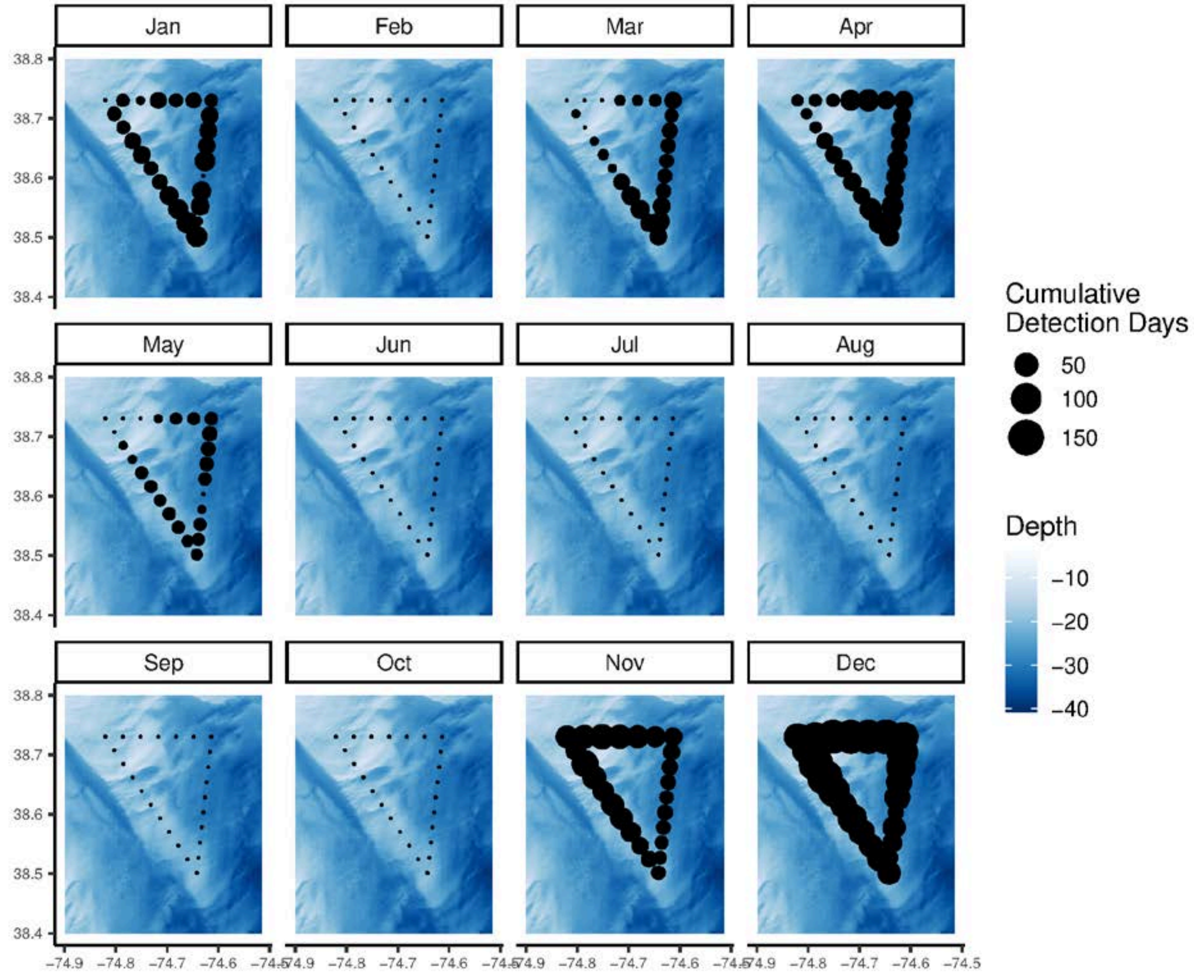

Figure B1.19. Spatial distribution of detections of striped bass on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all striped bass recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

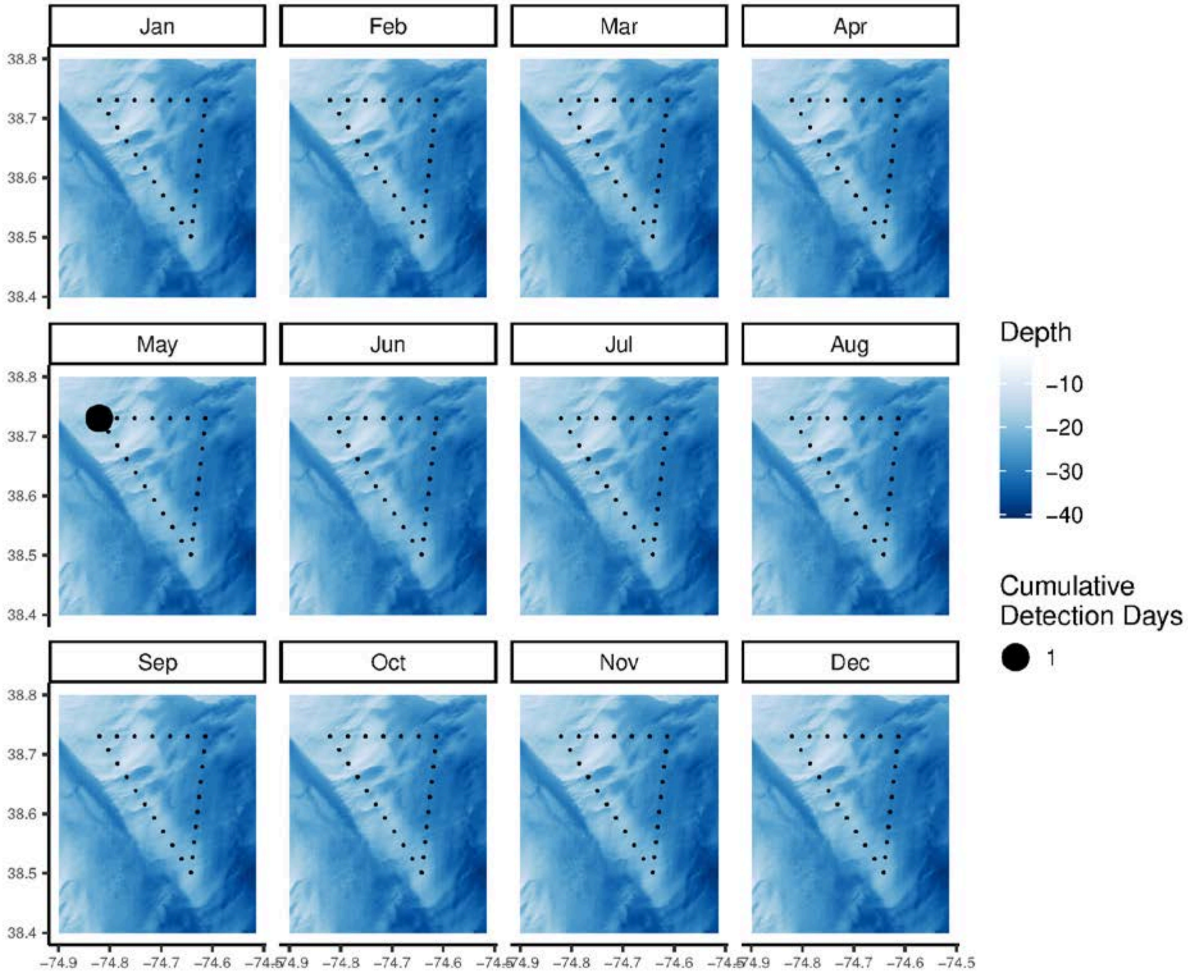

Figure B1.20. Spatial distribution of detections of summer flounder on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all summer flounder recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

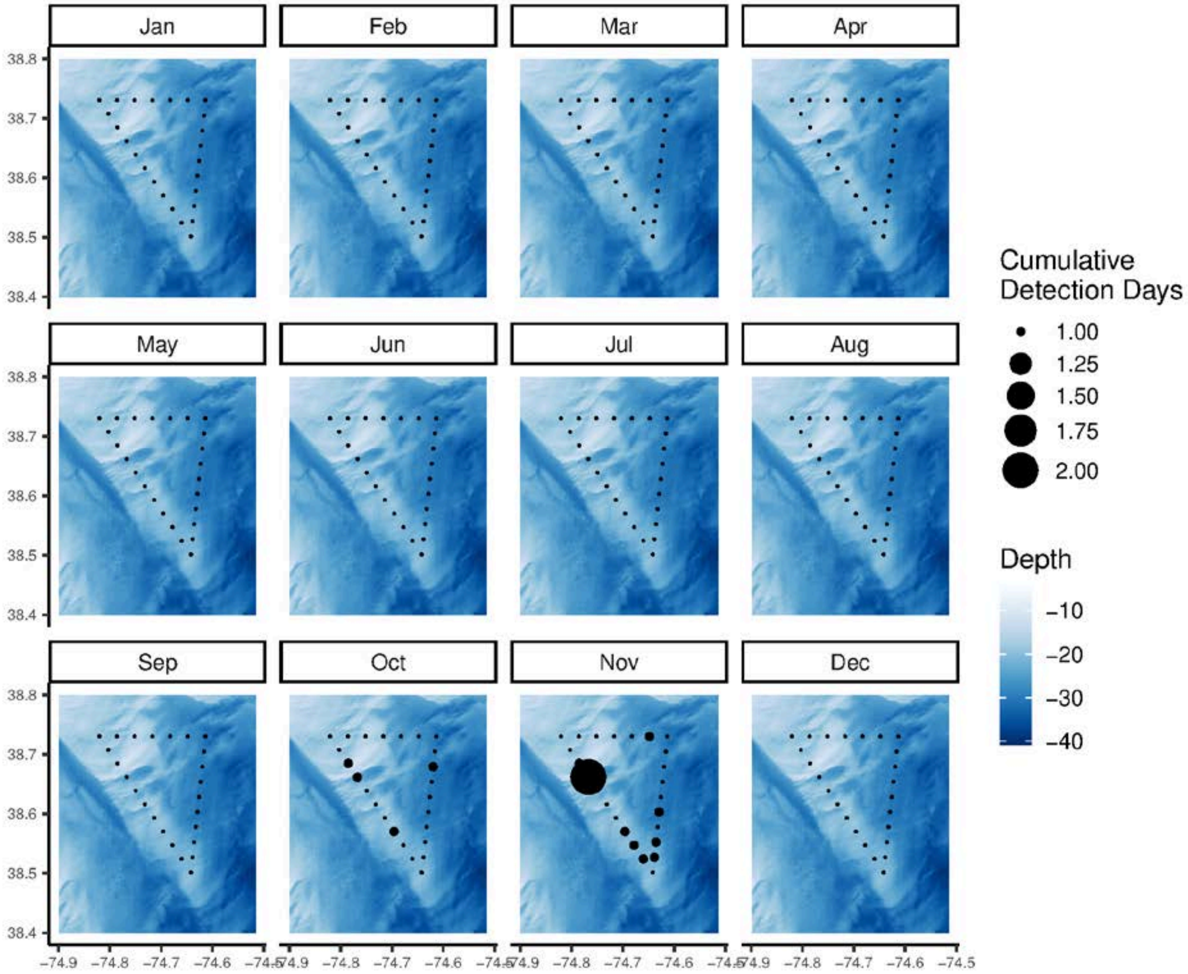

Figure B1.21. Spatial distribution of detections of thresher shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all thresher sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

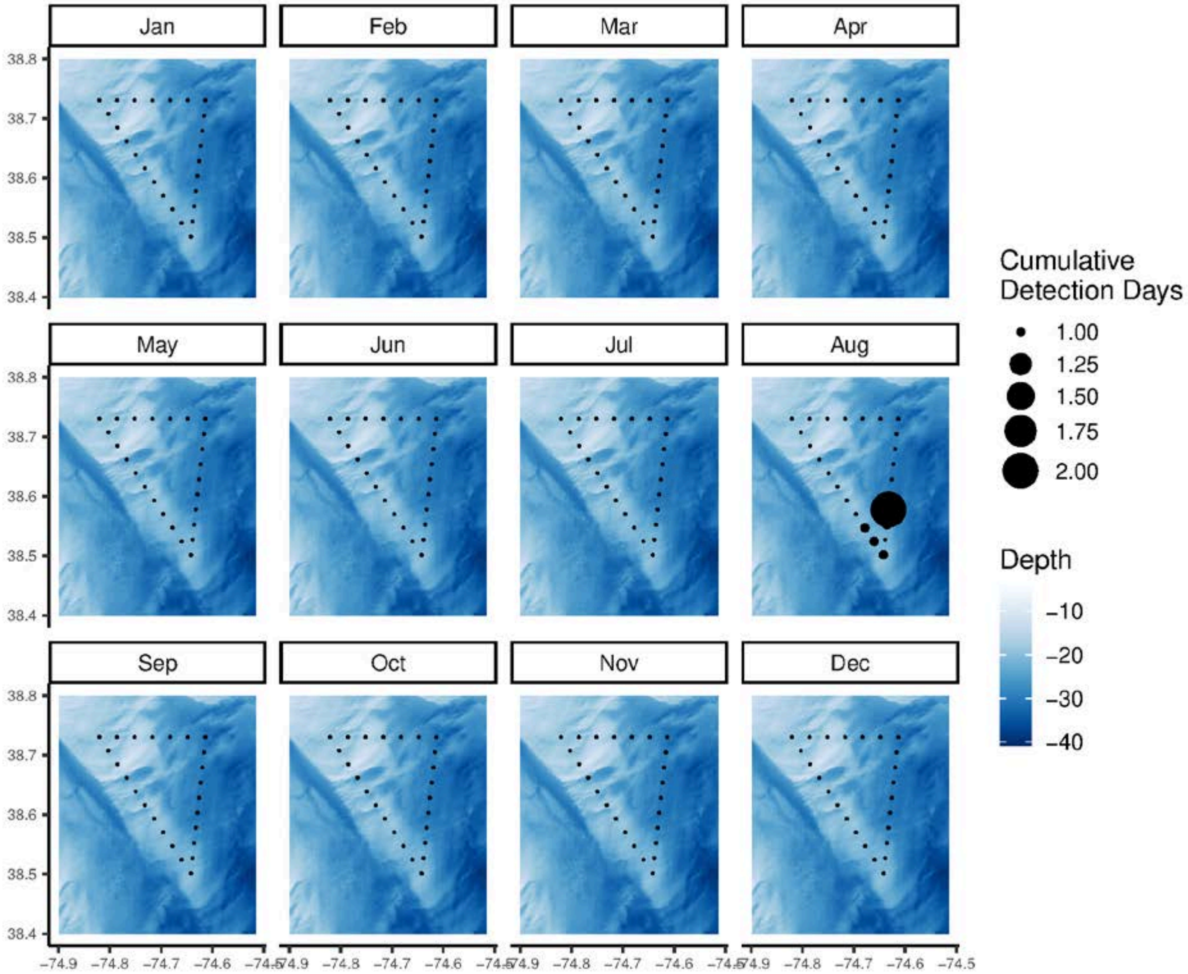

Figure B1.22. Spatial distribution of detections of tiger shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all tiger sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

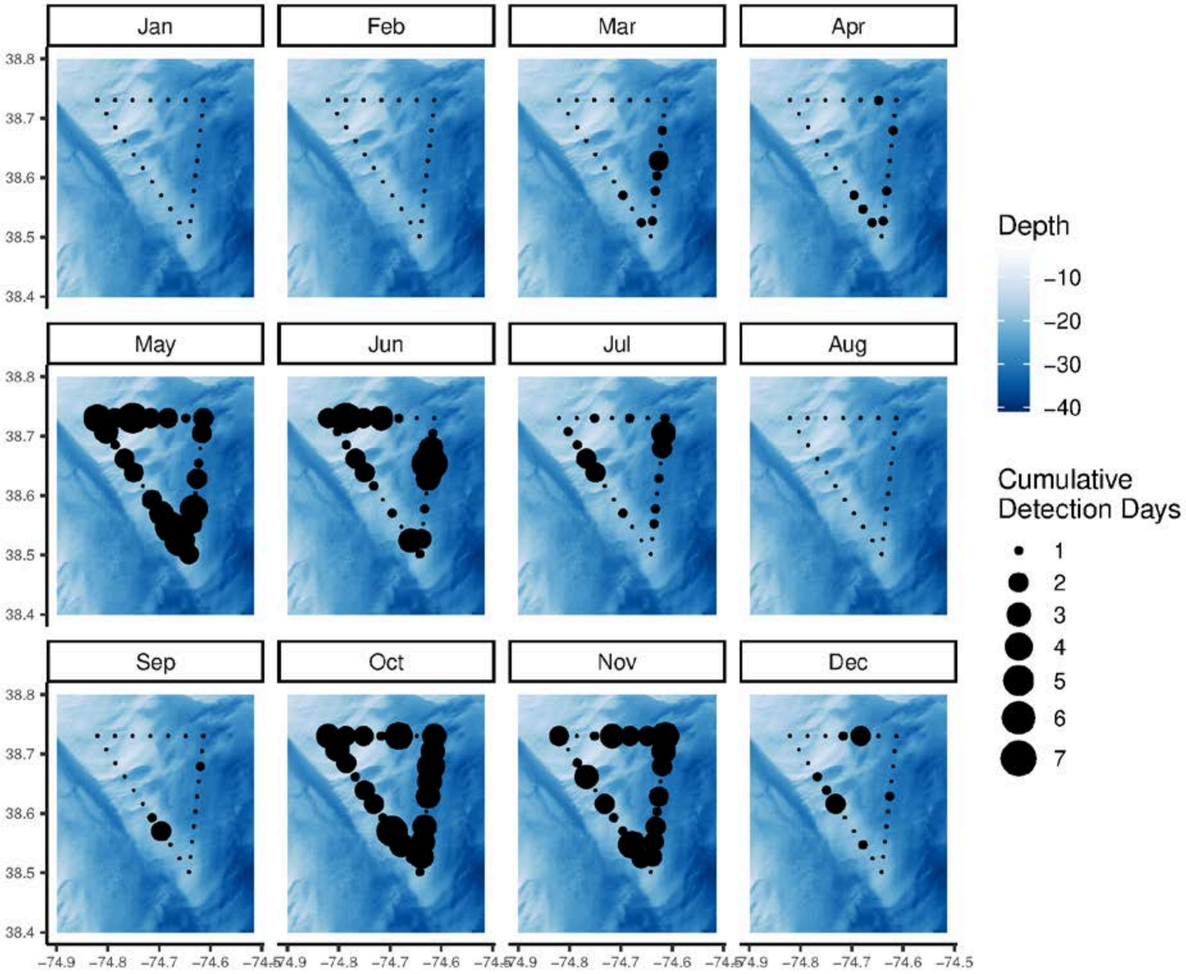

Figure B1.23. Spatial distribution of detections of white shark on receivers of the DE WEA by month.

Black circles represent receiver locations and are sized by the cumulative number of detection days for all white sharks recorded between 23 Feb 2017 and 27 Feb 2019. Underlying bathymetric map from NOAA National Centers for Environmental Information, US Coastal Relief Model.

Department of the Interior (DOI)

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The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM’s Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).